Empowering Communities
A Practical Guide to Energy Self Sufficiency and Stopping Climate Change

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This book explains the technologies used at Living Energy Farm, a community that is designed to operate without fossil fuel, and was developed at a modest cost so the tools and methods we use could be deployed worldwide. Living Energy Farm (LEF) has pioneered a unique set of tools. Over the past ten years, we have designed a DC Microgrid that allows us to live comfortably on renewable energy alone, year round. Our home is warm in winter and cool in summer, we can take a hot shower any time, run a refrigerator and washing machine, charge our devices and use the internet, grind grain and cook a meal, pump water and run machinery — all from renewable energy harvested on site, with very low maintenance costs. Our DC Microgrid supports a community of people who live on less than 300 watts per person, with no backup generator, and no support from coal, nuclear power, fracked natural gas, or industrial renewable energy systems. Our energy systems make grid power obsolete, in warmer climates at least, and possibly well beyond.

LEF continues to innovate in many areas, including food self sufficiency and regenerative agriculture, horticulture (growing food on trees), improved small scale grain harvesting equipment, farm-grown fuel for small farm machinery, biogas for cooking, solar air conditioning, and other technologies that allow us to live a gracious and comfortable life with very modest renewable energy systems.

This book tells the story of the work of many people. The author takes sole responsibility for the ideas and opinions expressed herein.

This book is being released without the use of a commercial publisher. It is an ongoing work in progress. This is the third edition of this book. (ISBN numbers remain the same.) We will continue to release improved editions in the future. Comments, questions, and suggestions for future editions may be directed to alex at conev dot org, or to Living Energy Farm, 1022 Bibb Store Road, Louisa VA, 23093, USA.

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Chapter 1 -- Which Technologies Actually Work vs What We Want to Believe

We generally think of the world of science and ideas as something that progresses forward, producing technologies that are more sophisticated and effective over time. Likewise, as regards social behavior, we think of ourselves as having progressed from darker ages of our pre-industrial ancestors. Such notions are an impediment to understanding both our social world and mechanical technology. Thus this first chapter is focused on helping the reader understand what is possible and what is not, what is easy and what is difficult, in building the world that will be created as industrial output declines. The answers will at times be different than most would expect, different than ill-informed notions of progress.

Being someone who has worked on buildings and machines all of my not-so-short life, I have been confronted many times by magical theories about energy. There are, supposedly, magnetic devices that can create perpetual motion, fuel pre-heaters that make ordinary cars get hundreds of miles per gallon of gasoline, electrolysis processes that can generate more energy than you put in, and so forth and so on. Any well informed person knows that “perpetual motion machines” are nonsense. But what no one seems to know is that technologies that are not profitable become invisible regardless of their efficacy. The implications are huge.

There is quite a bit of fuss in our time over energy. There are many who would contend we can generate enough solar and wind energy, store it all in batteries, and power modern industrial society with that energy. That belief sorely deserves to be challenged. But alas, as important as that may be, we are not going to do that just yet. We are more concerned with *what works*, because if we approach post-industrialism from a misinformed perspective, the results could be dreadful. Or they might be anyway, but let’s hope for the best and continue along.

One the solar side of things, solar electric panels (photovoltaic, or PV) are the focal point of an immense amount of hope, and investment. These panels operate at around 16 - 18% efficiency, depending on who you ask, and there is great anticipation that such efficiency might be improved. As the unwilling recipient of many “perpetual motion machine” theories, what might you think if I told you there were a “magic mineral” that can increase the efficiency of solar panels four-fold? That’s right, from less than 20% to near 80%! But this “magic mineral” has been rendered invisible by modern market forces, and dreadful notions of progress. What heresy! What conspiracy! Alas, before you put the book down I will give away the secret to the “magic mineral.” It’s solar thermal panels. Hot water and hot air panels operate at somewhere around four times the square footage efficiency of PV panels.

Soooo..... why all the fuss about PV panels when solar thermal panels capture *four times* as much energy per square foot? Because of market forces.

To install solar thermal systems, one needs to work with metal pipe, not the plastic pipe that now dominates the plumbing trade. The costs of skilled metalworking drives up the cost of solar thermal, particularly when those thermal systems are used in houses that are occupied by one or two people. By comparison, highly flexible wires are used to transfer energy from PV panels, not stiff metal pipes. Wires are much easier to install and connect than inflexible metal pipes that have to be soldered or threaded. Working with metal pipes is certainly simpler than building airplanes or automobiles, but the latter tasks are accomplished in highly organized factories, not out in the field. Contractors have to replicate buildings and energy systems in the field under varied conditions with such labor as they can find. The relative complexity and labor costs of flexible pipes versus stiff pipes are enough to create a bias among the builders who then pressure consumers to accept the product that is an easier profit for the contractor. I have worked as a contractor, and my point here is not to villainize that trade. It’s hard work for sure. The point is simply that markets do not favor technologies that work better. It favors quick-turnover profit.

The same pattern can be seen with appliances. The efficiency of household refrigerators *declined* from the 1940s to the 1970s. Federal regulations have increased efficiency since then to a moderate degree. Consumers buy cheap appliances with little concern for durability or efficiency. American refrigerators consume more energy than all the tractors on our farms. It's a big issue. A lot of people try to power ordinary refrigerators with solar power, and that does not work. We can talk about that later in the book.

The same comparison is true for other technologies. If one looks at roofing materials, asphalt shingles decay and have to be replaced every 20 - 25 years. Metal roofing lasts for decades, often many decades. The materials costs for metal roofing are only slightly higher than for shingle roofing. Metal roofing is clearly a much wiser choice, but shingle roofs cover the vast majority of houses in America. Why do so many people make a poor choice? As with solar thermal systems, building contractors can make quicker, easier profits with lower skilled labor installing the technology with much lower efficiency and durability. The materials cost of metal roofing is perhaps 50% higher than shingles, but the roofing contractors will often charge 1000% more to install metal. The metal roofing crews are few and far between. They have to be skilled and coordinated, at least to a small degree. The technology of metal roofing, though more complex than shingles, is about as complex as building a lawnmower. Not frighteningly difficult by modern industrial standards. But the difference is enough to nearly eliminate metal roofing from residential housing.

Apart from the "magic mineral" that made our solar panels four times more efficient, there is another technology that is even more impactful. That technology concerns scaling. Again we will give away the punch line so as to save the reader any excessive anticipation. The technology in question is cooperative use. To say that differently, renewable energy scales to ten people minimum. Here is why I say that. I have been building thick-walled, solar heated, cooperative (not single family) homes for a few decades now. The cost of these projects has been $14,000 - $20,000 per capita -- dirt cheap by modern standards. The very low cost is achieved by a reduction of square footage per person, simple but pleasant living spaces, and Amish style work parties. Imagine open, well lit, well ventilated living spaces, but not a lot in the way of marble countertops (unless we could find them used) or hot tubs. Strawbale construction is well suited to Amish style "barnraising" parties.

In the early 2000's, I did a very careful energy analysis of these facilities compared to ordinary American housing. I analyzed coops and private homes. All energy use within the home was accounted for and converted to standardized units on a per capita basis. The results were stunning in several ways. If we take 100% as the average American residential energy use, the range of my analysis went from 9% to 140%. All of the cooperative facilities were below 100%.

The private houses in the analyses were occupied by conscientious people. All of the free standing houses, regardless of how brutally low they set their thermostats, were above 100%. The lowest coop came in at 9%, and that was a solar heated strawbale cooperative house I had built at $14,000 per capita. Those were all surprising numbers.

The bottom line is that a slob in an apartment uses less energy than a saint in a free standing house. A free standing, single family house looses heat out of all four walls. An apartment has other apartments around it. Add to that the fact that Americans now occupy four times as much residential square footage per person as in the WWII era. The increase in per capita house size has rendered our improvements in insulation and efficiency completely ineffective.

Cooperative housing solves the housing crises because it is so cheap. It radically reduces energy use. It makes it possible to power homes and communities with renewable energy. It is a quiet miracle right in front of our very eyes. My analysis was some time ago, and I have pursued as much publicity about these issues as I have been able. Notwithstanding whatever limitations of charm the author might possess, it is clear that the idea itself of powering cooperative buildings with renewable energy is not something that Americans care to hear about, even if the alternative results in the destruction of the living Earth.

In spite of our tendency to focus on all the drama of our human-created world, the laws of physics don't care about our social life. The laws of physics, as they relate to buildings, machines, and what not, dictate that renewable energy systems have to be built, used and maintained by a minimum number of ten people to be cost effective and actually sustainable. There is also a maximum number of people that can effectively make and use renewable energy systems in sustainable communities. That concerns the transport of energy -- how far can one economically transport solar hot water or biomass? That limits the maximum scale of sustainable technologies, or at least the sub-units thereof.

By far, the most important technology -- one we will eventually adopt whether we like it or not -- is cooperative use. I sometimes refer to this as context -- what you do where. It is useful perhaps to point out that modern spatial arrangements of human beings in industrial societies is in no way an expression of "human nature" or inherent desires. How we live in modern American society has its roots in Roman society. The Romans used private property to replace tribal bonds. The Romans created the family farm as we know it. Prior to that modern arrangement, people everywhere lived in bands and villages -- small groups of people that were organized along kinship lines. Private property served to break traditional tribal arrangements, and to make the state the protector of individual rights. In Roman times, this was all done in society built on slavery, and only a limited number of people owned property (including other people).

The psychological attachment to private property is an insurmountable obstacle to effective implementation of effective energy systems in our time. That will change. We will all live sustainably in the long term, whether we like it or not. Our intent here is to plant seeds. In order to understand which seeds will grow and which will not, it is also important to address the marketplace of ideas. Those ideas that are most popular are *not* those which actually work well in the material sense.

Those ideas that propagate in academia and among NGOs (those organizations that do "development" work in non-industrial countries in our times) often do *not* support sustainable lifestyles even when they presume to. This represents a misallocation of many billions of dollars, and leaves us all less informed in the end about which technologies actually are sustainable.

Living Energy Farm (LEF) is a project on which I have focused in recent years. We built our buildings and created a renewable (no quotation marks) economy that could provide all of the domestic energy needs of ten people with about 300 watts of PV power and no grid electricity, no gasoline, no coal, no nuclear, no backup generator, no industrial "renewable" energy, and a tiny amount of firewood. (Tiny in this case means a couple wheelbarrow loads on an annual basis for ten people.) Our big innovation, unique to LEF, has been the development of a Direct Drive DC Microgrid (D3M). We will explore that in much more detail. In short, D3M means reducing battery size on solar kits by 90% and running most machines directly from the PV panels during the day. This approach is about 80% cheaper to build than conventional solar kits, and lasts the rest of your life with little maintenance.

It became clear to us that D3M could be of tremendous global benefit. We initiated projects in the Navajo and Hopi Nations, Jamaica, Trinidad, and Puerto Rico. The latter has to date been our most extensive effort. All of this has been done on a shoestring budget. D3M is, to quote a professor from Cal Poly in California, "radically efficient." Being so, it is ideally suited to low-income communities across the world. That said, we have found it difficult to promote this "radically efficient" technology over battery-based, AC (alternating current, like grid power) solar kits. That difficulty could, of course, be brought about by many variables. Having worked on this for a while, it is clear that a lot of people build their personal careers, and forward all manner of political agendas, while purporting to help low income peoples or the global environment. Our purpose here is simply to help the reader understand that *the popularity of a technology is not representative of its efficacy,* in any market.

D3M is a very important technology that we will talk about at length later on. One small victory we had in Arizona is illustrative. On the eastern side of the Navajo Reservation we found a woman who had a greenhouse in which she was trying to grow vegetables to eat and sell. When we came upon the scene, the water pump that watered her greenhouse was not working. She had purchased an ordinary solar kit that was battery powered. The batteries died, and were replaced a couple of times, until she had no money to replace more batteries. We (my wife, actually), cut the wires coming off the PV panels, cut the wire going to the pump, and connected the two sets of wires. For the cost of two wire nuts, she was back in business, and the charge controllers, batteries, and inverters were left unneeded and unused. If all the world understood D3M, the benefits would be huge. D3M is several orders of magnitude more cost-effective than conventional solar, but an awareness of D3M is not widespread. Again, the point is that *what works is not the same as what is well known.*

We have achieved a small amount of recognition and some funding from people who know us to help spread D3M and LEF's technologies. But generally speaking, D3M has not been widely embraced. The shorthand answer is that rich people don't want it and poor people can't afford it. Rich people have nearly unlimited energy on demand.

That's all going to change as industrialism declines. The big uncertainty is that we do not know the rate at which industrial output will decline. A managed decline could make it possible to maintain or even improve standards of living while energy and resource use decline substantially. Right now, it is easy, even with fairly modest income, to purchase tools and equipment to build sustainable communities. As industrial output declines, especially if the decline is rapid, that might be difficult or impossible. This is a huge problem. We hope to encourage people to do wise things sooner than they are compelled to do. In order to do that, you have to understand what works, not what is popular.

Back in the early 1990s I did some volunteer work for an environmental organization based in Colorado. The founder and his ex-wife peacefully cohabitated their sizable house with a handful of employees and volunteers. Back then the organization was well-known. The female side of the couple was a horse lover. She would swagger about the house, speaking with a pronounced drawl (that seemed to be the fashion in those parts), "Why cain't somebody make an efficient truck that will pull a horse trailer?" Notwithstanding the inherent trade-off between power and efficiency in gas and diesel engines.

I worked in the paddocks out back on irrigation plumbing. They were pumping water through irrigation hoses as large as my leg, blasting water high into the sky with big sprayers. With the dry, windy Colorado air going by, only about half that water was hitting the ground. The rest was blowing away in a cloud of mist. Meanwhile, out front of the building, there were some garden beds with some flowers and herbs, and some dainty little drip irrigation lines. The organization was already quite well known in those days, and there were tour groups almost daily. They would come by and "oooh and aaah" over those little drip irrigation lines.

The female side of the couple was a vehement anti-vegetarian, with books titled "Tofu-Free in 1993" lying awkwardly among the other environmental literature on a table. The house itself was passive solar. From a thermal perspective, it did quite well in the cold Colorado winters I am sure. The windows were at a modest slope to the sun, and would thus let the summer sun stream right in. (Passive solar usually uses vertical windows on the southern side of a building such that the winter sun comes in but the summer sun does not.) I was there in the summer. At the high altitude of that location, even summer is not all that warm. It snowed on the fourth of July in the hills around us. Still, the place did get quite warm on those summer afternoons. A much more fundamental problem was the construction itself. I prefer strawbale as something that is cheap and easy. This house had no strawbale. It was poured concrete, in two layers, with foam (isocyanurate) in between, and semi-subterranean as well. The partially underground approach is smart in a dry climate. But that much concrete has a massive amount of energy embedded in it. The cost of such a building, in terms of both embedded energy and money, is far too high to be widely applied.

Both the male and female counterparts of that endeavor, long since separated, are famous. A simple internet search reveals many books, awards, etc. (The male is more famous than the female, a household name among well read people.) The organization itself now has many offices, hundreds of employees, and hundreds of millions of dollars in funding. Obviously, there has been from the beginning a certain measure of hypocrisy in their work. In the bigger picture, that is not so important. There are two other points that are far more important. The first is the same we are making for metal roofing and solar thermal. *In the environmental realm, the information that is most heavily popularized is not the most environmentally benign or technologically well developed.* It is rather the “information” the consumers find most comforting. The second point is simply that over time, because of the willingness of our leadership to sell comfort at the expense of truth, and consumers to buy it, deeper truths become extinct over time. When you look back even further, there is a long chain of information dating all the way back to the Greek scientists from over 2000 years ago that has effectively gone extinct because of the desire of privileged people to rationalize that privilege.

As for our famous friends from Colorado, they are certainly smart people, and genuinely morally concerned. How is it that such bright people could screw up so badly? That organization now promotes “electrification,” as does the modern environmental movement generally. The idea that we can replace fossil fuel in modern industrial society is fairy dust -- another perpetual motion machine, except one that is actively supported by millions of the most well educated people in the world.

It’s not so hard to see what is going on here. Empire is the process of setting up large social systems that concentrate wealth and power. Others have referred to the empire as a “super-organism.” It is certainly a large, powerful system that far supersedes the lives of the many individuals who participate. The middle and upper classes of empires old and new always consider themselves to the holders of enlightenment, compassion, education, and “culture.” They always hold on to the idea that their privilege can be had by everyone on Earth, as long as all of those people participate in the system. Participating in modern American society means holding on to this same set of biases. The participants in modern industrialism, without really thinking about it, deny the existence of the 90% of people who are too poor to live as they do. That is the fraction of humanity that does *not* own a car, 90%. Our Colorado friends, along with the dominant spokespersons of modern environmentalism, passionately support the spread of electric cars, and “electrification” more generally. That approach casually denies the existence of the vast majority of people left out of the upper layers of the modern industrial empire. It is simply an unquestioned habit at this point to do so. Be all that as it may, the point here is that *the inherent biases of Empire cause wide realms of information to go extinct.* We lie to ourselves a great deal, not just about politicized issues, but about many mechanical technologies. Then we are surprised with devastating consequences.

What will human villages look like a few hundred years from now? Will they be horrific little patriarchal groups governed by warlords? Will they be sustainable, tolerant, feminist societies? Sustainable mechanical technologies do not in themselves guarantee any outcome as regards the social culture of future society, but sustainable technologies at least make it *possible* for us to live as we would want. I don’t know if we will be able to make PV panels centuries into the future, or even bicycle tires. I can tell you that we cannot power a technological society for decades and centuries into the future with PV electricity and lithium batteries. That is as undeniable as gravity.

The critical point here is to understand that an affordable and effective post-industrial economy -- whether we are talking about a household or the bigger picture -- cannot be implemented by taking existing machines, appliances, and buildings and simply powering them with “renewable” energy. That simply will not work. That is, of course, the current direction. And it is disastrous. “Solar” has become a mass deforestation campaign as tens of thousands of hardwood forests are bulldozed and paved to build PV fields. This is the My Lai Massacre moment of the modern environmental movement. That refers to the village of My Lai that, during the Vietnam War, was massacred in order to save them from communism. Now we are destroying the forest of the Southeastern United States *five times faster than the Amazon Rainforest* in order to save it. Not only is this emblematic of the moral debasement of environmentalism, at a practical level, powering the old economy with “renewable” energy just will not work.

You need to understand these basic facts. Our sustainable future is going to be built by small groups of people to satisfy local needs. ***Energy use will be focused on community design first, and then thermal considerations.*** Once those pieces are in place, then one can build D3M and biogas systems. Direct drive and biogas are much more accessible than the rest of the long list of fairy tales (batteries, hydrogen, cold fusion, or perpetual motion). You cannot order sustainability in a box that is delivered to your door.

The transition to a sustainable economy has to be a matter of absolute devotion to our Sacred Earth. We have to overcome the pressures that cause us to restrict our awareness. In industrial society, we are smart with our technology, but very stupid in our future planning. Modern industrial society is structured to concentrate wealth and power. We are taught to think of ourselves as independent actors, when many of our personal choices are highly influenced by social pressures that serve to concentrate power in the larger society. To say it in such blunt terms seems reductionist, but when you extrapolate the point over time it becomes clearer.

If the country of “Conservationia” began conserving resources and re-organizing themselves to be more locally self sufficient, the big factories would slow down, some would cease production altogether. Human well-being could substantially improve while resource consumption dramatically decreased. The natural world would bloom with new growth. For many decades, various writers have advocated such. A partial list would include E.F. Schumacher, Kirkpatrick Sale, Hazel Henderson, Mohandas Ghandi, and many others.

Meanwhile, on their western border, the country of “Consumptionia” rolled along, using up as much as they could. Their factories expanded production. The environmental impacts were large, but their overall production of metals and manufactured goods climbed. The same factories that make automobiles make weapons of war. In this story, Consumptionia conquers Conservationia, then collapses.

In Consumptionia, everything was grid powered, there was only marginal use of “renewable” energy systems added to the highly consumptive systems developed previously. No coal or gas powered electrical generation plants were shut down because of solar fields (which is true in the U.S. now). The point here is that our conception of “renewable” or “sustainable” technologies is based on the prior structure of our economy, which is set up as an empire that concentrates wealth and power, including and especially military power. These are the reasons we make so many foolish choices about energy. It is time to end the massacre. It is time to save ourselves from our own self-imposed ignorance.

Chapter 2 -- Rubbish Homes and Energy Independent Cooperative Housing/ Co-Living

Working class people often live in badly insulated, drafty buildings, and pay a heavy price for it. They pay very large energy bills, and are at risk of freezing to death in winter when energy supplies are restricted for whatever reason. Wealthy or poor, almost all Americans live and work in buildings that consume a lot of energy. Over 40% of climate change emissions are caused by creating buildings and keeping them habitable. It is truly mind boggling to consider that much more thermally stable buildings that use no external energy sources at all could be built at a fraction of the cost of even the cheapest house trailer. This is not just theory, it is something I have done many times.

The people who freeze in trailers instead of building thick-walled homes are not stupid. They are compelled, as are all of us, to function in our modern, class-stratified society. If you walk down the street wearing extremely ragged clothing, you would not be well respected. You might face harassment or even arrest, depending on circumstances. That is the primary reason why mass manufactured trailers, as well as middle class homes, that consume enormous amounts of energy are preferred to homes made of local materials that stay warm while consuming almost no energy. At least a trailer represents modern, respectable “clothing.” It is also true that your average person, rich or poor, simply does not know how to build any kind of building, let alone a well built, well insulated home made of local materials. For these reasons, massive financial burdens are borne by low income people, and there is a huge environmental impact from all housing. This chapter is going to teach you how to build well insulated buildings, either from manufactured materials you buy at a lumber store, or from rubbish.

Energy Independent Co-Living (EICL)

LEF was built in an area where several “intentional communities” already exist, and the original design was influenced by those communities. LEF is extremely energy efficient. In some intentional communities, there is a lot of sharing of kitchens, living rooms, and bathrooms. There is enormous financial and environmental benefit from that level of sharing. But most Americans are not accustomed to that much sharing.

In considering how to help other people live at similar levels of efficiency as LEF but without quite so much sharing of space, we have created the concept of Energy Independent Cooperative Housing, or EICL. The idea of EICL is that each person or family would have their own “unit” or apartment in a shared wall facility with other people. The thermal shell would wrap around the outside of multiple living units. The thermal support systems would be shared, including space and water heating. There would be one biogas system, and one D3M. It would be modeled on LEF’s energy systems, but with more privacy. And each unit would be privately owned, so the owner could hold and build equity. Instead of paying hefty energy bills, the residents would pay a monthly fee that would go to a caretaker. The caretaker would watch after the thermal systems, throwing switches when needed. They would take care of the biogas system. They might also put your clothes in the washing machine and put your dinner in the Insulated Solar Electric Cookers (ISECs) while you are at work. You would come home to a warm house and a hot meal. You could eat in your own space or in the living room with other people. We are hoping that EICL could make LEF scalable in the social sense -- something that would appeal to a lot of people.

Rubbish Homes

EICL, or indeed any building, can be built with new materials or “rubbish.” Rubbish in this case simply means whatever you can find -- discarded materials, or organic materials like straw or bamboo. The difference between a building built with commercial materials compared to a rubbish home is mostly just time. The building trade thrives on standardized materials that can be assembled quickly and predictably. The idea of rubbish homes and EICL are two independent concepts. We are discussing them both here because super-insulated rubbish homes are actually quite easy to build, and can reduce our environmental impact enormously. And because of the community aspect of EICL, rubbish homes are a good match for EICL. Rubbish homes are much easier to build if you can do it with some group support, like an Amish barn raising. That said, the two concepts (super insulated rubbish homes and EICL) are not necessarily dependent on each other.

Constructing highly insulated buildings is neither expensive nor difficult. They can be built with a mixture of trash (rocks, broken concrete), organic materials from farm and forest (bamboo, leaves, straw, newspaper), and/ or modern commercial materials, new or discarded. Such buildings can be homes or commercial facilities. They can stay warm in winter and cool in summer. They can support residential, agricultural or commercial functions without grid power, nuclear energy, fossil fuels, or other forms of industrial "renewable" energy such as solar farms or windmills. Such buildings are well insulated, not designed for maximum resale value to wealthy customers.

Environmental Solutions are Always Local

Beware that what works great in one place would be foolish in another. A subterranean house that works great in New Mexico would be a horrible mold pit in Virginia (absent significant mechanical ventilation). A strawbale house would work great in the Dakotas, and it would be foolish in Miami. Environmental solutions are always local. Most of what follows here is focused on temperate and cold climates. If you live in a tropics, then some of what follows below will not be relevant. In warmer, climates, protection from insects and decay, as well as ventilation, are primary concerns. That may favor smaller, separated buildings instead of the larger facilities we build in colder climates.

Good Design, Not Just PV Panels

When I teach green building workshops, I talk to the participants about three levels of planning to consider, each an order of magnitude more important than the one below. The most important level is context -- what are you building, where, who's using it, and for what purpose? The single family house on a mountaintop may have some appeal, but if you are driving an hour to work, another hour to pick up the kids and go shopping, and coming home to shovel firewood into the woodstove, you cannot add any "environmental" technology onto that situation to make it sustainable. Poor context means isolated. Good context means building the right thing in the right place. Though Americans often prefer isolation to interconnection, by far the most important environmental "technology" ever developed is cooperative use -- in a word, community. Community is *the* technology that makes renewable energy viable.

The second order of magnitude is conservation and insulation. It is always cheaper to save energy with good insulation and conservationist design than to generate energy. I have seen many people rebuild old houses, putting fiberglass insulation in those thin walls. Three inches of fiberglass is a shade better than nothing, but 18" of any cellulosic material will perform dramatically better. I have also seen many people, particularly in recent times, add PV panels to poorly insulated buildings. That's kind of like putting solar panels on the wings of an airplane. PV panels have become a green badge, something to display. Adding PV panels to a poorly insulated house does *not* decrease the environmental footprint of that house. We have to change how we live, not wear green badges.

Renewable energy sources are the third level of design consideration. Renewable energy when added onto conventional American buildings is a feeble supplement to fossil energy sources. Once one has considered appropriate context and developed wise conservationist design, energy use is reduced by 90% or more. Then renewable energy becomes a powerful, liberating energy source that can allow us to live sustainably, and support communities that empower our democracy from the ground up.

Cheap Foundations

If you want a building to remain stable over the long term, the foundation needs to be non-compressable, stable materials that reach below the frost line. The frost line is highly variable, being much deeper in very cold locations. That said, you have many options. The cheapest foundations would be made with a rubble trench or similar techniques. I have seen buildings made from with dirt bag foundations, though I would be concerned about the dirt bags deteriorating over time.

If you have ever seen the aftermath of an earthquake, you know that even a very small amount of steel (rebar) goes a long way to prevent a building from shifting. A small amount of concrete between rocks in a rubble trench would also help stabilize the foundation, but that is not critical. Helen and Scott Nearing advocated that approach, using forms to simply drop in rocks and a little bit of concrete. That’s fast and easy. If you have to, you can do it without concrete, as long as the rocks are in a trench. The rubble in a rubble trench can be rocks, bricks, or any “urbanite” you can find. That’s a general term for cracked concrete or similar materials.

There are three places where modern industrial products are very helpful in constructing a well insulated, comfortable, inexpensive home. Those three are roofing metal, windows, and sub-grade insulation. In this latter category, we need something that reduces the conduction of heat while not biodegrading. Commercial foam works well. The two kinds of foam used in the building trade are styrene and isocyanurate. The former is cheaper, and comes as expanded or extruded. Any foam will work as foundation insulation. It is also possible to use discarded foam in whatever form it can be found. Used foam can also be purchased to save on costs. (We have used a company called Insulation Depot, https://insulationdepot.com/)

Thick Walls

All of what follows as concerns thick wall insulation is equally applicable to retro-fitting existing buildings or building from scratch. Adding a bit more insulation than most people use is not a good level of insulation. I have made super-insulated walls with straw, crumpled newspaper, leaves, and bamboo. Super-insulated walls need to be 18 inches or so thick.

Post and beam buildings may have an aesthetic appeal, but that is one of the most expensive ways to build. Small and single story buildings have less load than larger or multi-story buildings, thus tolerating lighter construction technique. I have built a number of buildings with neither posts nor wooden studs. It is a bit tricky to give advice on that count. Inexperienced builders often build in a manner that is much heavier or lighter than is needed. It takes some experience to know what size and configuration of materials will work.

That said, I have used bamboo on a number of occasions. The cheapest walls I could imagine would consist of lateral saplings or bamboo poles at the top and bottom of a wall, with vertical saplings or bamboo poles functioning as studs. Nailing or lashing can be used for saplings or bamboo. A layer of chicken wire can be put over the saplings or bamboo. Lacking chicken wire, smaller sticks or pieces of bamboo could form a lattice. This whole configuration is done twice, once to form an outer wall, and once to form an inner wall. Then the space between the walls is filled with whatever you can get your hands on, packed moderately tightly. Beware that foam used above grade is a powerful fuel if the building burns. I have used many materials to fill in walls.

The big advantage of strawbales over other forms of infill materials is that bailed straw is much faster. The last house we did, we had a crew and stacked 400 bales around the whole house in a single day. That was a retrofit. Other materials can take much longer. The straw is also tighter. There is less oxygen inside the bale. That means that a strawbale wall, once covered, will not burn, at least not easily. Tighter straw makes for better insulation as well. But lacking bales of straw, one can use many other materials.

It is possible to put stucco, or earthen plaster, right onto straw walls without any chicken wire. If you have chicken wire, the wire helps hold the wet stucco on when you smear it. Without the chicken wire, the stucco tends to just fall right off. It requires some persistence. The chicken wire helps stabilize the stucco, both short and long term. The chicken wire itself is cheap, but not an ideal material. The best material would be expanded metal stucco lath. That material is surprisingly expensive. The problem with the chicken wire is that the mesh, even with fine mesh chicken wire, is so open that the stucco does not adhere well as it is being applied. It works, but it's annoying as the stucco wants to fall off too easily. A finer mesh material like hardware cloth would be better, whether it were plastic or metal. One has to balance cost considerations.

Fastening the chicken wire or other mesh to wood studs or saplings can be done with small staples, even a hammer tacker. For bamboo, lashing the wire to the bamboo poles is necessary. You can't staple bamboo poles. In between the studs or vertical poles, we make staples with barbs on the end (see drawings) to help fasten the wire to the straw.

One issue with rubbish walls is that they are a habitat for ants and other insects. If they are not tightly packet, rodents can move in as well. We use borate, particularly in the lower part of the wall. One can purchase roach powder. Some straw bale enthusiasts spray on boric acid. My understanding is that borate breaks down to boric acid, though I am not entirely clear how that might play out over time in a wall. The cheapest borate we have found is borate laundry detergent, Borax being a brand name.

There are a few myths about strawbale that are worth addressing. The "breathability" issue raised in some strawbale manuals is bogus in most environments. That issue is raised as regards lime and cement plasters. (As regards terminology, cement refers to either the dry portland cement powder before water is added, or the wet substance once water is added. We call the hard, cured/ dried product concrete. In this case, the terms mortar, stucco, and cement plaster can be used to refer to wet or dry, soft or hard, substances. All of these things are made from sand and cement, as well as other ingredients.)

Cement stucco is fine and your walls do not need to "breathe." The exceptions are walk in refrigerators, spaces that are in any way commercially refrigerated, indoor swimming pools, commercial shower houses, commercial food processing facilities, roof leaks, plumbing leaks, buildings constructed in northern woodland environments that never dry out, or buildings in tropical/ subtropical climates. Any of those situations can create a lot of indoor moisture that can then condense in the walls. Condensation inside the walls simply does not happen in buildings in temperate climate areas with normal use.

Wall Surfaces and Ceilings

Long ago, I was trained as a volunteer firefighter. Part of that training concerned how a fire behaves inside of a house. There are at least two issues in this regard as concerns walls and ceilings. One concern is how long it takes a fire to burn through something. Coverings that help contain a fire are beneficial. The second concern is flame spread, or whether a particular material helps or hinders the spread of flames. Sheetrock (drywall) scores very well on both points. That and the fact that it is relatively cheap has allowed sheetrock to become the dominant interior covering in modern buildings.

Any wooden surface is going to have higher flame spread characteristics than sheetrock. The ability of wood to contain a fire would vary considerably depending on how the wood was installed, what kind and how thick the wood might be. I am not suggesting that interior walls should never be covered with wood. But interior earthen plaster or other non-flammable coverings will improve the safety of the building, and make it less likely a small fire would turn into a catastrophic one.

Some folks in the popular strawbale movement advocate for exterior lime plaster. I am not so fond of that personally. The plaster is not very hard. It is easily damaged and buildings have to be re-plastered over time. In very dry climates, some kind of lime plaster or adobe would be fine presumably. I have always built in eastern U.S. I prefer to mix in some portland cement into the sand-lime mix, which effectively turns it into stucco. I am aware that there is a lot of energy embedded in cement, but in this case, a small amount of cement adds a lot of durability to exterior plastered surfaces. That seems more sustainable to me.

The material that goes in between bricks or blocks to hold them together is mortar. Mortar smeared on a wall is stucco. The basic ingredients in mortar or stucco are sand, lime, and cement. Commercial mortar also has some agents that fluff up the mortar so that it stands up a bit when you lay in on a brick. This allows the bricklayer to adjust each brick slightly. For stucco purposes, you are not worried about the fluff. Mortar, stucco, and indeed anything made with cement, can be made with varying ratios of basic ingredients depending on your intentions. More sand makes a mix cheaper. Lime makes it sticky, softer than cement, and lime is cheaper then cement. The cement makes it stronger and harder, but it is the most expensive ingredient. If one purchases commercial mortar mix, Type N (N for normal) has less cement. I would use that on a first coat outdoors, if I purchased commercial mix. The second coat can be Type S (for special). That has more cement.

If you want to mix your own mortar mix, the rule of thumb mix is three parts lime to one part portland cement. Then tree parts sand to one part of the lime/mortar mix. But you can vary these proportions considerably. I have seen mixes up to 6 parts sand, though that gets quite soft. Generally, I would put two coats of stucco on exterior walls. The second exterior coat has two extra ingredients. If you are building in a climate where you get horizontal rain from storms occasionally, then some water proofing is in order. There are many paint or spray on water proofing materials for masonry. These could wear or flake off over time. I prefer an admix that goes into the mortar mix itself. The material we use is Type E mortar. We used to import this stuff. Now it is available. (Search for Type E Krystol Mortar.) If you don't want a cement gray building, you can either buy tinted mortar mix, or concrete dye. The latter is cheaper, though you have to measure things carefully to keep the tinting consistent. Without spending quite a lot of money, you are going to have muted colors. Still, a sandy brown or a burnt red seems preferable to cement gray.

For the interior of strawbale walls, you have more options. There are many books and articles on "natural building" that include instructions on earthen plasters. That is not my choice, though I have seen some other folks do it with good results. My approach is to do a first coat with just plain clay. That can take a week or two to dry. Beware that one is introducing a lot of moisture into the building. Lots of ventilation and dry conditions are needed. The clay will crack quite a bit as it dries. That's fine for us, as the cracks help hold the thin coat of stucco that goes over it. Note that this wall covering approach is very cheap, but if you hit the wall hard, you knock a hole in your stucco. It's easy enough to patch. Interior stucco can be painted. The roughness of the stucco can be challenging. A paint sprayer is fast, though you need good breathing protection if you go that route.

I could imagine doing walls of free materials by simply making a lattice of saplings, sticks, bamboo, or anything on hand. If you have some wire mesh to go over that, then great. Either way, an earthen plaster over that would seal it all up, on the interior at least. It is my opinion that a multi-layer clay/ earthen plaster and stucco work well enough for fire resistance, but you work at your own risk here.

A ceiling is more challenging. It could be done, if you have no other choice, with a lattice of sticks and earthen plaster. That would be messy. If you can afford sheetrock, that would be the place to use it. In the attic in a cold climate, we want R-50 to R-60 of insulation. The R value measures the insulation value. Note that half inch drywall nailed to ceiling joists or trusses two feet apart is not strong enough to support that much insulation. The ceiling might come down on your head. I have mostly used 5/8 inch drywall that is glued and screwed. Drywall jacks are cheap(ish) and a lifesaver. The 5/8 drywall has fiber in it and is much stronger than the half inch drywall.

One should note that commercial cellulose is about one-third fire retardant by weight. That's a lot of fire retardant. People have asked me about using straw in a ceiling for insulation. I would be concerned about fire risks. A hot attic in the summer would be a place where a small fire would turn into a raging inferno almost instantaneously. Perhaps one could use some straw and cover it with commercial insulation. I have not tried that. I have seen recipes for homemade cellulose insulation with fire retardant. That could be another approach, though I have not done that.

Strawbales added to existing buildings have to be raised up off the ground to give them some separation from soil moisture. An eight inch gap between biodegradable materials (wood, straw) and the soil is desirable, more is better.

Strawbale buildings can be built using a lot of unskilled community labor (your friends!). The simplest, fastest way I know of to build super-insulated walls is to use strawbales stacked inside a conventional (and cheap) stud frame design, or stacked outside of an existing house. Years ago, I spent a lot of time looking at load-bearing strawbale, only to realize that the steel rebar pins and cabling needed build a load-bearing strawbale is much more expensive than the wood used to build a stud wall. A stud wall is also much cheaper than post and beam. Straw bales are simply leaned up against a wall by unskilled labor, then stuccoed, again with unskilled labor. A good stuccoer can radically accelerate your unskilled stucco workers. Inexperienced stucco workers can move very slowly if not taught properly. When I am teaching people stucco, I tell them, "Just smear it up, if you are doing it carefully, you are doing it wrong." Then I might come behind them and touch up a bit.

Windows and Roofing Metal

The two ingredients to building where you really need commercial materials are windows and roofing material. Good windows are expensive. In theory, you can put straw around a house on the inside of the walls without replacing or moving the windows. But if people are already living there, then they probably do not want to give up the interior space. Putting straw on the outside means that you would be better off with new windows at the outside of the walls. Moderately expensive double-pane windows will perform like very expensive triple-pane windows if thermal curtains are used. Never, never, never rebuild and install old single pane windows.

I have done a number of strawbale retrofits. I build a lightweight footing outside of the existing building footing. Exactly what that looks like is dependent on circumstance. Foam is used below grade between the lightweight footing and the original building footing. Extra space if filled with gravel or whatever. We build wooden boxes around the windows, and if you can afford it, install new windows. The straw is tied to the existing wall with tie wire. In this case, there are not studs to speak of to hold any chicken/stucco wire in place, so we use lots of homemade clips.

A well built strawbale wall can tolerate some moisture, but decent roof overhangs are wise on any building where it rains. Strawbale aside, I have seen a lot of damage in ordinary houses from short or non-existent overhangs. In some cases, we have had to add rafter tails and extend the roof a bit. That involves pulling off the facia, and screwing in short sections of wood to extend the roof.

Ventilation

Avoid dead air spaces, especially in any climate with damp summers. Everything must cross ventilate. Traditionally, houses in warm humid climates were built up off the ground, with high ceilings. People swept and cleaned their naturally ventilated houses, and they were not full of toxic mold. I grew up in a house in southern Georgia where you could throw a rock off the front porch and splash it in the swamp water. With no air conditioning and no de-humidifiers, traditional southern homes were not excessively moldy.

If you live in a much drier climate, then less ventilation is probably fine. Study how people traditionally built in your area. Many of the mistakes I have seen come from trying to implement the same building style in many diverse climates, and constructing buildings that can only function properly with constant energy inputs.

Avoid Leaky Buildings

Unless you are building a teepee, flat, straight building lines are cheaper, faster, and will yield a much tighter insulation shell. A flat ceiling is better. Clearstories, dormers, and skylights are always heat leaks. Put your creativity into making an effective shell look and function better. The American norm is to sacrifice function to making buildings look like micro-mansions. "Creative" buildings that leaks like heck and have a PV panel on the roof are not cheap to live in, and do not have a small environmental footprint.

Function Before Form

Plan your utilities and energy systems as an integral part of the design, not something that simply has to conform around the edges of a pretty design. I always put the utility room in the middle of the bath and kitchen so pipe runs are short. Similar logic -- make it work well first -- is applied to all energy systems.

Resources

Good source for reclaimed foam insulation for sub-grade use, or for building homemade solar heating panels http://insulationdepot.com/

Waterproofing admix we us in exterior stucco, cheap and nontoxic, much better than just adding a spray-on water seal. Type E mortar, available from various suppliers. As much as I hate to endorse corporate suppliers, Home Depot has Type E mortar. Search for Type E Krystol Mortar.

If you do use skylights, here is a design than can convert them from a thermal liability to a thermal asset. These can be homemade as well, with aluminum roofing metal, http://www.zomeworks.com/sunbender/

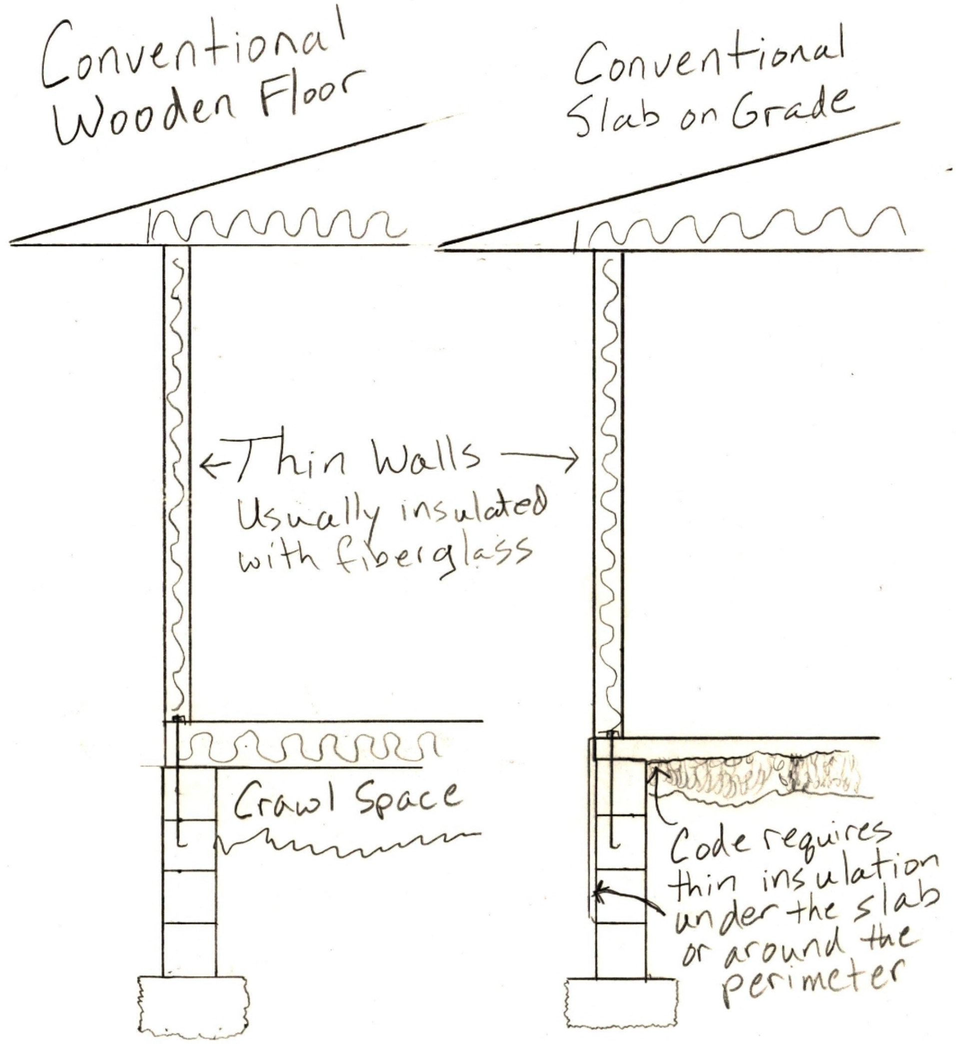
Solar hot water pumps, closed loop only, see ussolarpumps.com

Other solar hot water components, including very high quality stainless water tanks http://www.aetsolar.com/

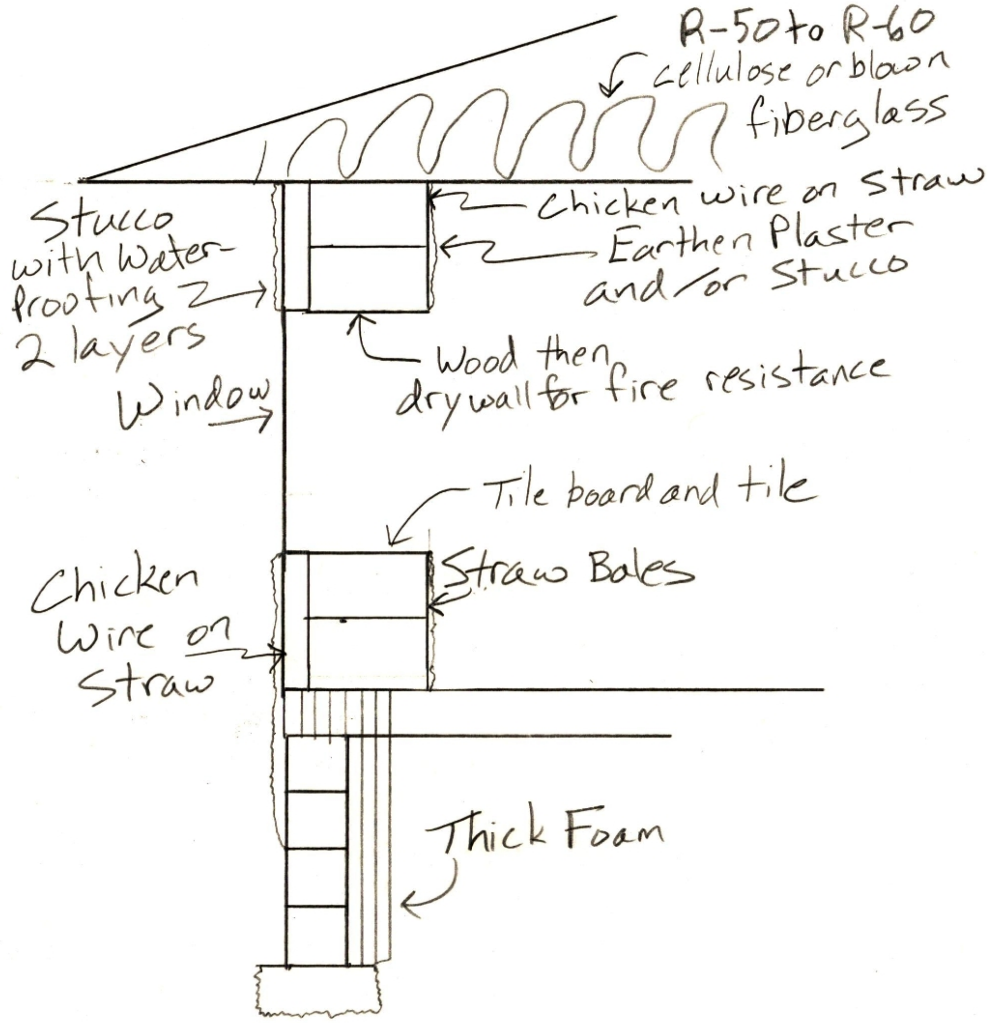
High quality, moderately priced wood fired equipment, DS Machine in PA. Great Amish company, they have water heaters, canners, furnaces, and other useful devices. https://dsofpa.com/

Good design for thermal curtains, https://www.instructables.com/Insulating-roll-up-curtains-that-cut-heat-losses-t/

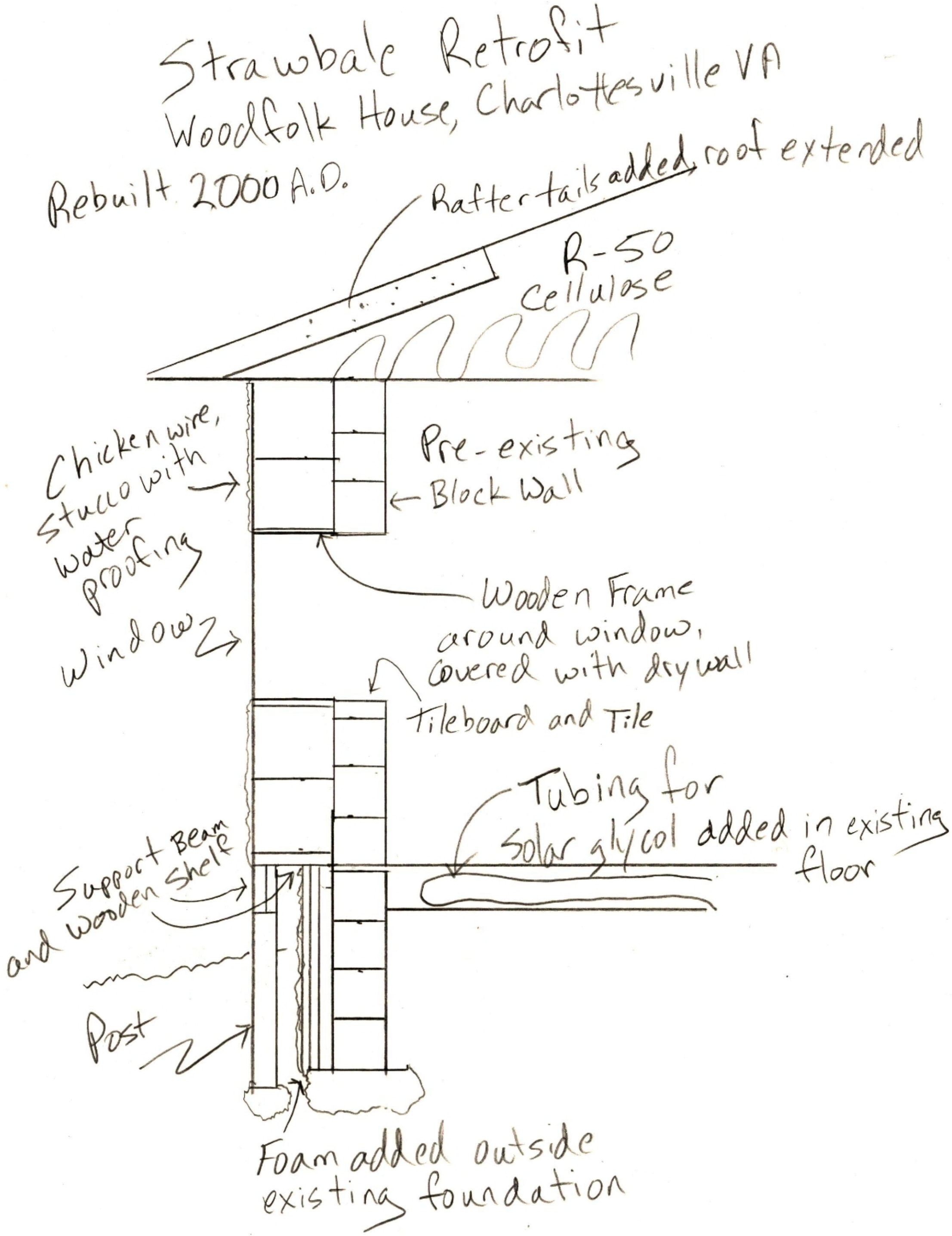
Conventional Construction



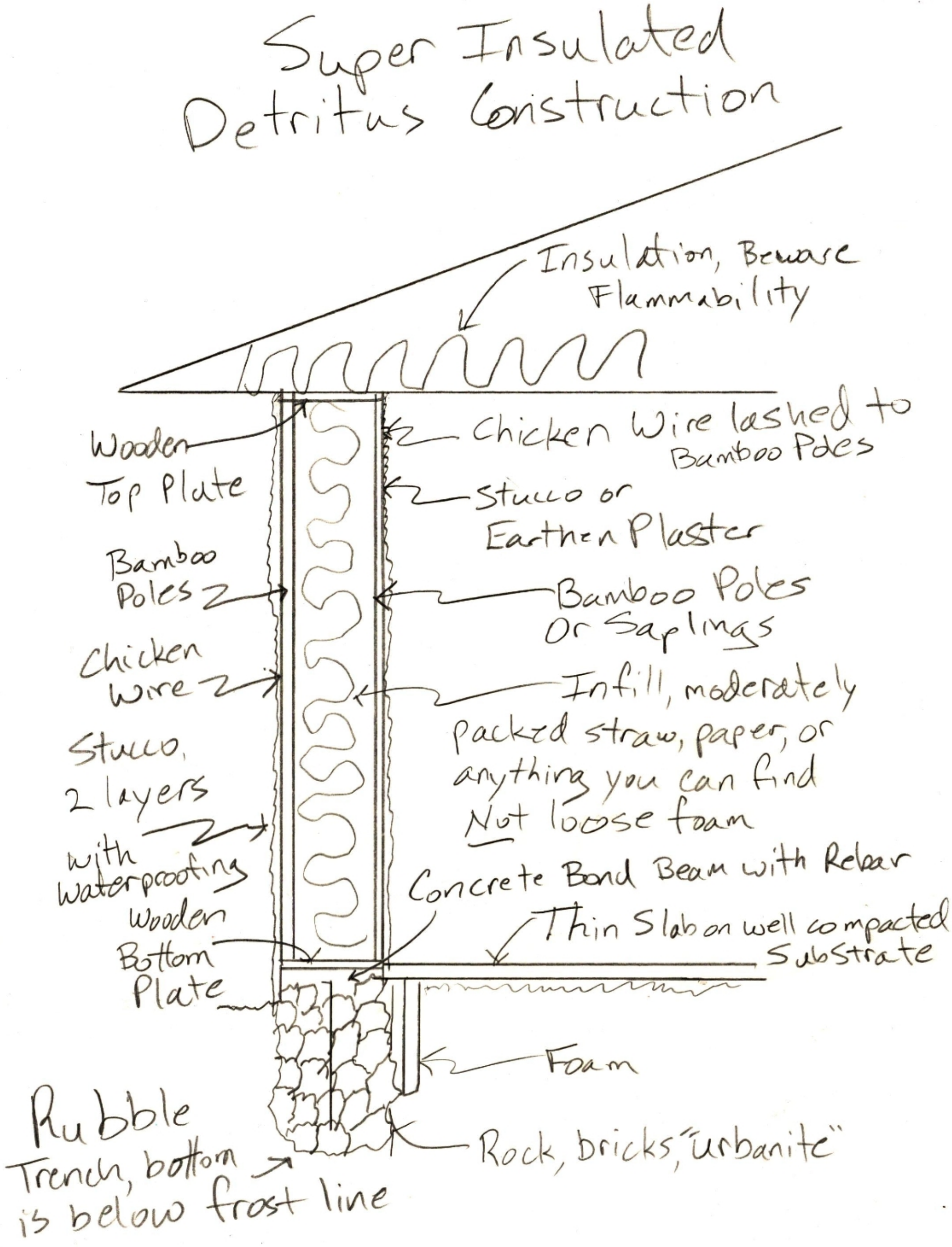
Super-Insulated House with Strawbales



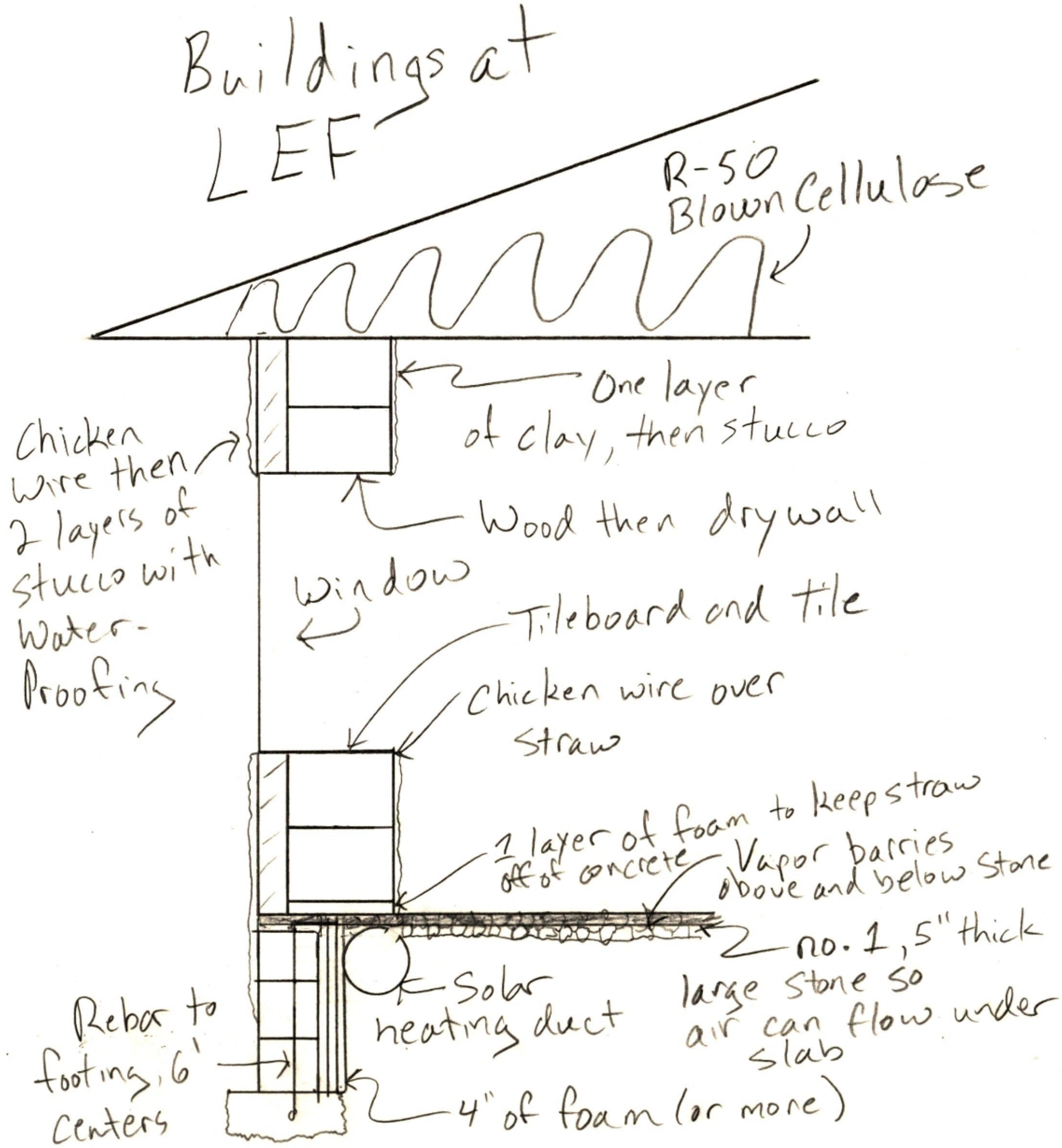
Strawbale Retrofit



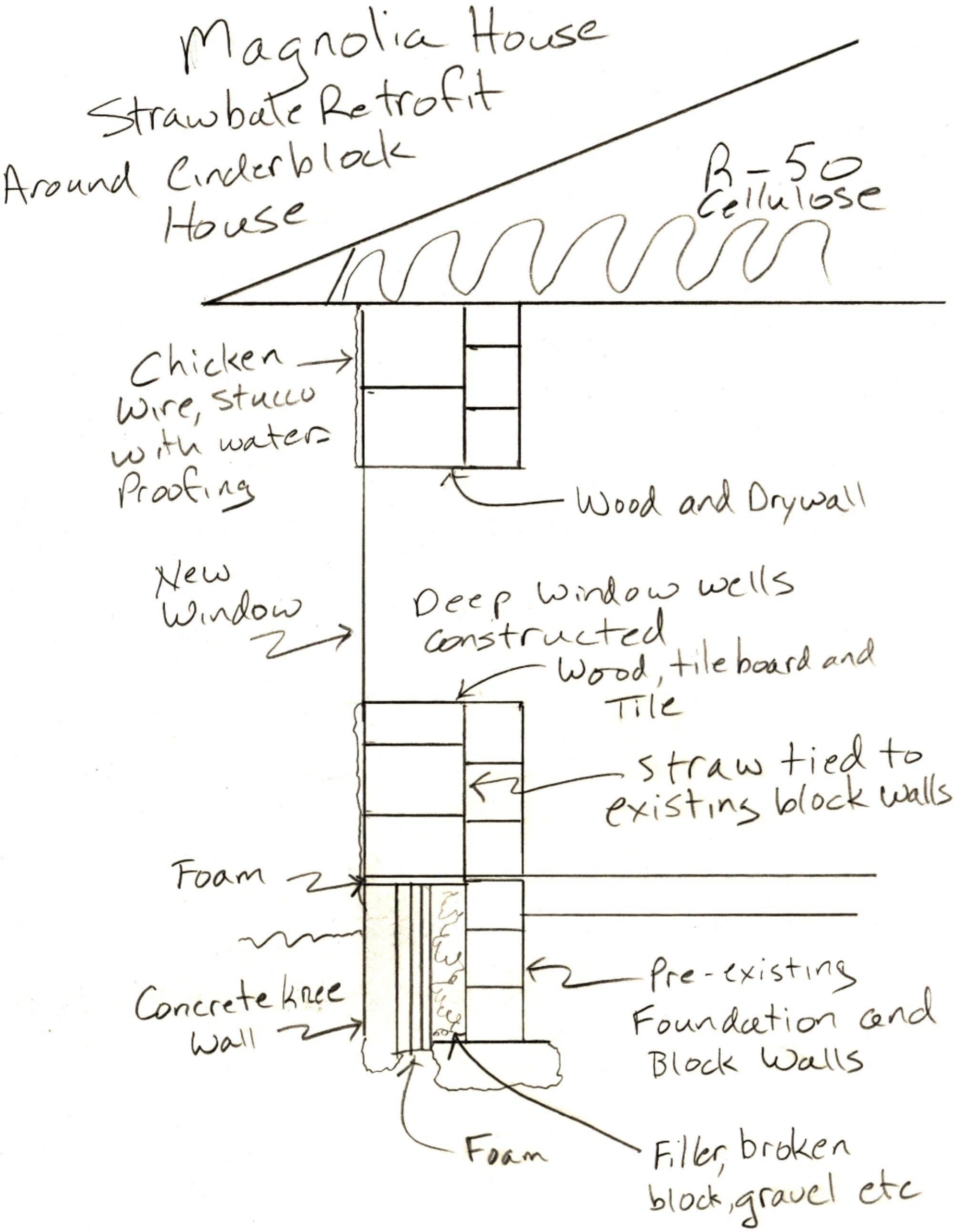
Detritus Construction



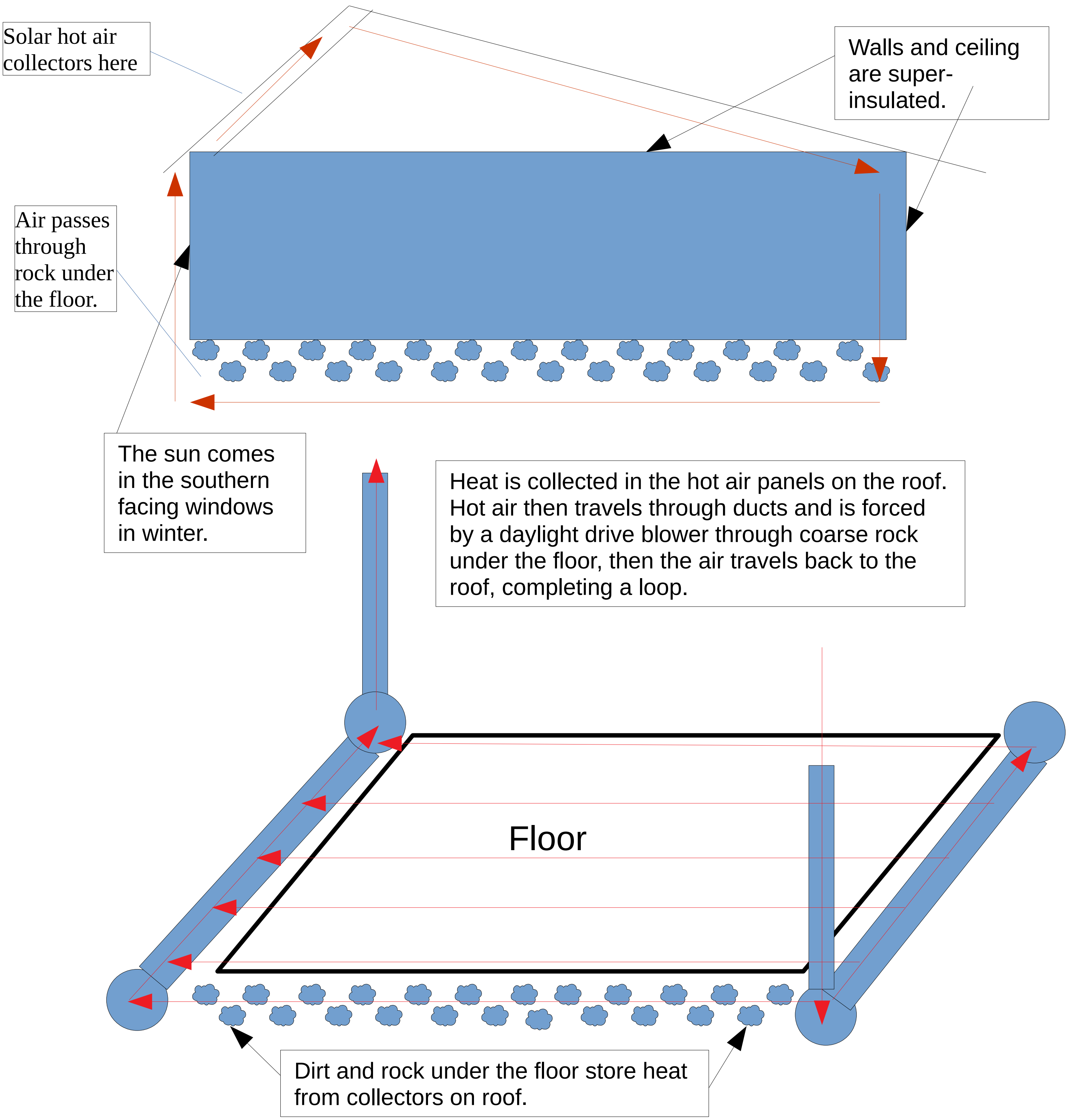
Buildings at Living Energy Farm



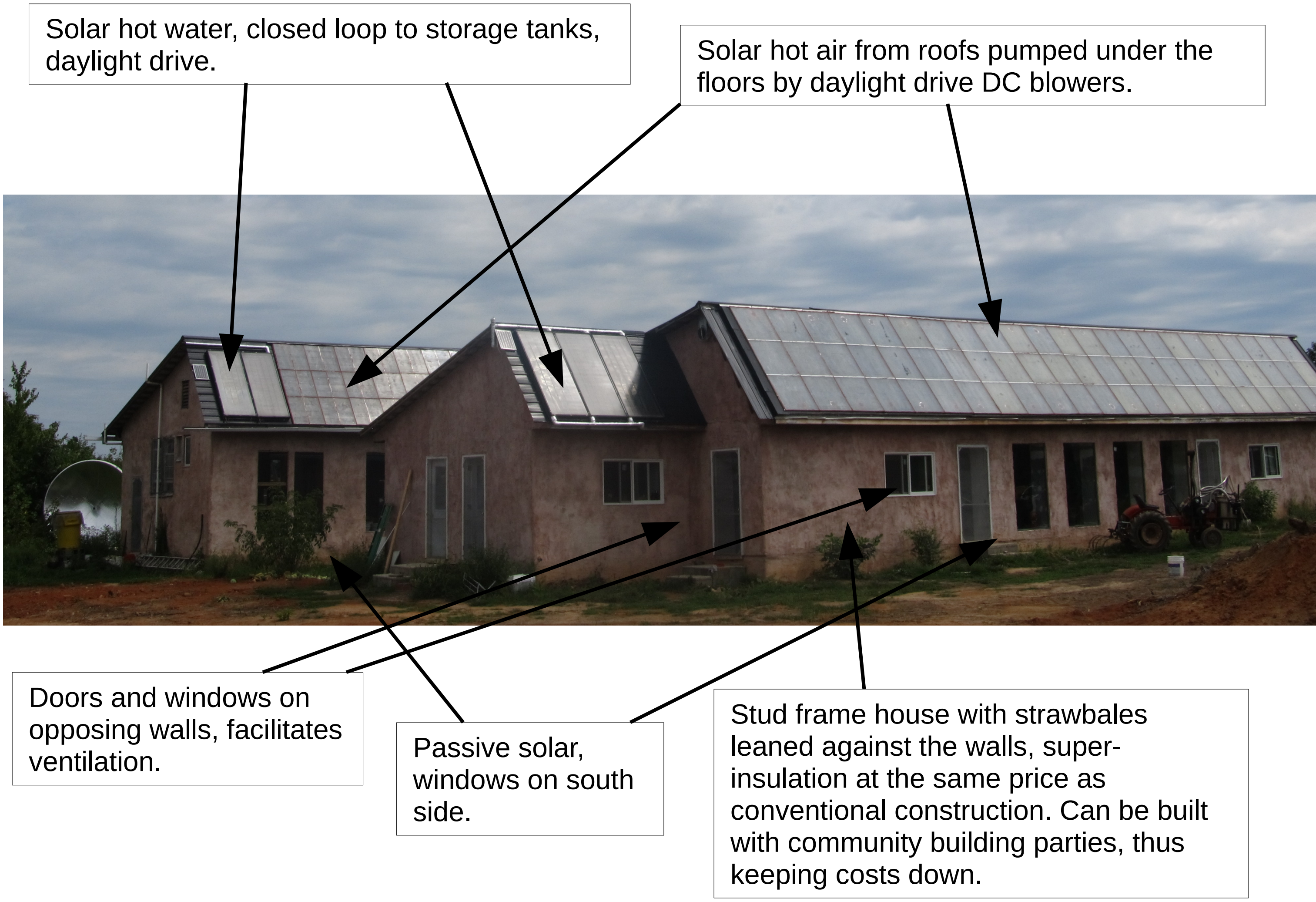
Strawbale Retrofit



This diagram shows air flow in the buildings at LEF. Leveraging involves using DC electricity to capture large amounts of thermal energy using industrial DC motors. Absent a daylight drive DC electrical system, this design would not make sense. This system captures a huge amount of heat, and makes extensive use of thermal storage. Notice the heated air passes under the floor, not into the living space.



The main house and kitchen at LEF. These buildings make extensive use of leveraging.



Chapter 3 -- Keeping Homes Warm with Solar Energy

How Solar Thermal Became Invisible

Do not even think about adding solar features until you have worked out the questions of context and insulation. I have seen some really expensive and ineffective solar heating and power systems added to poorly located, sparsely occupied, badly insulated buildings. The results are terrible. Solar photovoltaic power is your last priority. No joke. Let's flesh this out a bit.

I was visiting some friends of mine recently. They are an extended family living in a passive solar house that was built in the 1970s. The house was reasonably well built and well insulated. It still has the original metal roof. They have done some maintenance and minor upgrades to the house, repairing the insulation shell as needed. The house is in the Midwest, and I was visiting in late October, so the nights were a bit frosty. I am tallish and thin, so I generally wear heavier clothing and use more blankets than most people. In this case, the house was quite comfortable. I stayed a couple of nights, and one thin blanket was quite fine.

Nearby live some other friends of mine who live in a very well known "ecovillage." I visited with some folks there on the same trip. We met in a new, smallish, private house, where even at dinnertime there was already a raging fire in the woodstove. This new house had no solar thermal features at all. Instead, they were burning large volumes of 'renewable' energy, even on sunny days. How did we get so lost?

In the case of this "ecovillage," the houses are all private. Most are occupied by one or two people. They all have prominently displayed PV panels on the roofs. Survival in a corporatist (I prefer not to call it capitalists, as it bears no resemblance to the smallholder capitalism advocated by Adam Smith) involves earning and spending, buying and selling at a profit. Ordinary Americans buy and sell houses a great deal. A spacious, well decorated but poorly insulated house sells for a lot of money -- far more than a smaller house, or one with beneficial thermal features. It's the same thing that happened to refrigerators as regards energy efficiency falling as people make choices to purchase handsome "clothing" at the expense of functionality. Buying and selling houses is a cornerstone of our economy. Our "ecovillages" hand out green badges in the form of PV panels. Good design and cooperative use get abandoned.

Setting aside the ideological overhead about living in ecological virtue, a passive solar home is the same price as any other. And you can cut 70% or so off of the heating bill, enjoying those brisk nights in a warm home with no heat input from wood or fossil fuel. Solar thermal never was profitable in the corporatist economy. In our time, unprofitable means invisible, so solar thermal has been left behind.

Passive Solar Thermal

There are many large volumes written about passive solar design. Consult them at your discretion. The basic rules are simple. The axis of the building -- the long length of the rectangle -- is oriented east-west so that that long side of the building faces south. Along the south side, put lots of windows. The rule of thumb is that the length of the roof overhang is the same as the distance from the top of the window to the top of the wall. You need to think about your latitude. In Virginia, the winter sun angle is 30 degrees. The winter sun pours in our south facing windows. In the summertime, the sun is overhead, and does not come in the south facing windows, protected as they are by an appropriately sized overhang. It is beneficial to have yard, gardens, and orchards on the south side of the house to keep your solar clearing open. East and west of the house, you want small trees that will shade the house on summer mornings and afternoons, but not shade your solar collectors. I prefer semi-dwarf fruit trees in that application.

If a passive solar home is well insulated, it will stay warm most of the winter with no additional fuel. Occasionally, in the spring and summer, even on a very bright day in winter, the house might get a bit too warm. It's easy enough to cure that by opening a door or window.

The term *passive* solar refers to the fact that no pumps or blowers are used. The warm sunshine simply comes right in. I have seen quite a bit of attention given to thermal mass in passive solar design. It's good to have thermal mass inside of a well insulated shell as it tends to stabilize temperatures, which is beneficial year round. That said, the thermal mass issue is sometimes oversold and misunderstood. The first rule is that heat goes up, not down. The worst designs I have seen involved overhead thermal mass. That does not work at all. Other designs include trombe walls or water tanks that are supposed to absorb heat during the day and then release it. That approach is of limited value. A living space has to maintain a fairly narrow temperature range, perhaps 65 to 80 F, depending upon the preference of the occupants. Seventy or eighty degree air simply does not heat up standing walls or water tanks enough to make a big difference. The inside of an actual thermal collector (hot water or hot air) can easily climb well above 200 or even 300 F. Thermal conduction is geometrically proportional to temperature difference. High temperature air or water transfers heat. Room temperature air does not.

My personal feeling is that adding thermal mass to passive solar design in which the thermal mass does *not* have the sun shining directly on it is not worth the trouble and expense. That does not take away from passive solar in the broader sense. As I said, in most climates, a well insulated, passive solar building will stay warm most of the year.

To return to our earlier subject thick rubbish walls (which in this context includes strawbale), a thick wall shack built with discarded materials and passive solar design stays comfortable most of the winter. Even in bitter cold areas, if the walls are thick and there are some windows on the south side, the indoor temperatures would never reach levels that threaten the occupants with hypothermia. Think of it, all the millions of buildings built across the industrial world, and they all could have been built with thick walls made of any fluffy material, and the occupants could live in them with never a threat of dying from the cold, and a 70% (roughly) reduction in energy bills. We have avoided this path so individuals can wear high status "clothing." We are destroying our living Earth for the sake of high status clothing and now green badges. We have to turn this around or the entire system is going to collapse, either from limitations of energy supply or from pollution, or both. Wake up!

Active Solar Thermal

Having built a number of buildings with thick walls, passive and active solar features, I like active solar thermal systems. We will talk about our Direct Drive DC Microgrid (D3M) in another chapter. For now, suffice it to say that D3M and active solar thermal work together very well.

Active solar thermal systems use pumps or blowers to move heat from solar collectors into the building. A house with active solar will stay much warmer in winter than a house with only passive solar. The reasons active solar homes are even rarer than passive solar homes has to do with a few factors. As Americans' homes have grown so much larger, solar heating systems to heat large, sparsely occupied houses have grown in a commensurate fashion. Note, the *per capita* cost of housing that is cooperative, well insulated and solar heated is much lower.

The traditional design assumption of all of the active solar systems I have seen is based on an assumption that the people living in the house are mindless, and that the solar heating system should mimic a fossil fuel heating system. This results in over-designed solar systems where heat is collected from large, expensive collector sets, and a complex set of valves and controllers is used to push heat into storage tanks. Then later on, heat is pulled out of those storage tanks to keep the house at the requisite two degree temperature differential. Such systems are too complex and too expensive.

The active solar heating systems I have built are simpler, much cheaper, and effective. The setup at Living Energy Farm has worked well. Our buildings there have air-based radiant floors and direct drive blowers. The solar heat storage mechanism is a high-tech material under the floor called dirt. When the sun comes up, the homemade, inexpensive hot air collectors start to warm up. The blowers start to turn, and heat is pushed under the floor. As the sunlight intensity increases and decreases, the blowers speed up and slow down, until at sundown it all stops. It is truly a delight to hear those blowers humming during the day. Yes, we wear sweaters in the winter, and tolerate more than two degrees change in temperature. That said, we can, in our straw insulated, passive *and* actively heated house, live with no fossil fuel and no firewood at all if we choose. For comfort sake, we burn a wheelbarrow load or two of wood in the darkest months of winter for hot water when we have long cloudy spells. But with a buildout cost of less than $20,000 per capita for the building and all its energy systems, it is revolutionary in the context modern lifestyles. The per capita cost, and embedded energy cost, of the project in Colorado I mentioned earlier is probably ten times as much. The firewood consumption of a more well known ecovillages is two orders of magnitude higher than our design.

The crippling aspect of our approach as regards promotion is that we share space and utilities. Bathrooms, living rooms, and kitchens are shared with the LEF design. Most people want more privacy than that. We are hoping the Energy Independent Co-Living (EICL) will be better suited to American needs for privacy, and equity, and thus will be more marketable while retaining the environmental benefits of our design.

As regards the details of active solar heating systems, I have done it a few different ways. I have built radiant floors using flat plate collectors (the same kind as are used on hot water systems). Our most recent retrofit involved tying flat plate collectors to existing radiators in an older home. That does not work as well as a radiant floor, but sometimes you work with what you have. Overall, radiant floors are strongly preferred. The design at LEF has air-based radiant floors. That is cheap and effective.

As regards collectors, you can use liquid or air-based systems. Solar hot water collectors are highly efficient, and durable. In my nearly 40 years of working on these, I have never seen a flat plate collector fail on a closed loop system. Those systems run on water and glycol, so the metal inside the collector does not corrode over time. (See chapter on solar hot water.) They last a long, long time. Water is much more dense than air, so moving heat with water and glycol (antifreeze) means only fairly small pipes are needed. A 3/4 inch pipe can carry enough heat to heat an entire house. There were more solar thermal systems built in times past. Sometimes the collectors can be obtained on the used market very inexpensively. New flat plate collectors are expensive, but very effective if you can find them. Pre-manufactured solar hot air collectors are not widely available. They are not hard to make.

The radiant floor system we have at LEF is based on the movement of air. The collectors are homemade and inexpensive. I am sure the per-square-foot efficiency is not spectacular, but with the low cost, it is easy enough to have a larger collector, which is what we have. With water/ glycol systems, the circulation cannot be allowed to stagnate. The liquid would boil. With air based systems, that problem is eliminated, and you simply run then or not whenever you please. It is truly a pleasant feeling to hear the blower humming, knowing that it will keep us warm that night, knowing that we don’t have to cut firewood or burn any fuel at all to stay warm.

Firewood

Firewood is not “renewable” if everyone uses a lot of it. Keep in mind that the United States was almost entirely deforested to support firewood demand prior to the Civil War. That’s when and why our forebearers switched to coal. One of the most important books ever written about this subject is titled *Poverty and Progress,* by Richard Wilkinson. It discusses these issues most elegantly. The knowledge of our own ecological history is under threat of extinction, even (especially) among the wealthier and educated classes. That is why we are engaging is mass deforestation to send wood pellets to Europe, and putting ethanol and biodiesel in fuel tanks -- because of our own, self-imposed, ignorance.

A cynical assessment of modern "green" building is that wealthier people hide behind their green badge solar panels while consuming a large volume of resources. Poorer "ecovillages" and single family homesteaders often hide behind mountains of firewood while consuming a large volume of resources. It is no coincidence that such consumption makes the American empire more militarily powerful. Lots of green badges, and the next generation pays the price. The alternative is simply good design that puts context and real conservation (good insulation) ahead of energy production. Then solar thermal can be installed, and lastly, PV and biogas.

Chapter 4 -- Solar Hot Water

Solar hot water is a very useful addition to any self sufficient community. For better or worse, building solar hot water systems in cold or temperate climates requires more skill than hanging PV panels. In warmer climates, simple batch collectors are easy to build. What follows is a general guideline to designing and building solar hot water systems. You may need to consult other resources as well, depending upon your intentions.

Batch Collectors

Batch collectors are by far the simplest and cheapest form of solar hot water system, and by far the dominant kind in use around the world. You can either make one yourself, or buy a manufactured version. We can discuss both here.

The manufactured units have a collector (vacuum tube or flat plate) with a tank at the top. The water in the collector gets hot when the sun shines, and then thermosyphons up into the tank. The term “thermosyphon” is what it sounds like -- a syphon driven by a difference in temperature. In this case, the hot water in the panel rises up into the tank. Another pipe allows cooler water in the tank to travel to the bottom of the collector. Some old tractors and household hydronic heating systems use thermosyphons. If you ever try to make a homemade thermosyphon, you should be aware that you need larger pipe sizing than on a pumped system. A thermosyphon is weak compared to even a small pump.

There a couple of things to know about these water heaters. They are meant for warmer climates where the water in the collector cannot freeze. If the water in the collector were to freeze, it would shatter the collector. In colder climates, you will want to use flat plate or vacuum tube collectors where the solar fluid is pumped to storage tanks. We will talk about those shortly.

Homemade Batch Collectors

Another option is to build your own batch collector. If you can find the materials, this can be done very inexpensively. Also, homemade batch collectors are a bit more freeze resistant than the vacuum tube or flat plate units, though even homemade batch collectors are not really suitable for far northern climates, unless they are restricted to seasonal use.

You will need a water tank. Your options are to either buy a new electric water heater, or find one that got discarded because of a remodel or a bad thermostat. Avoid any super-fancy electric water heater tanks with plastic linings or anything like that. Stainless tanks are great if you can find them. Otherwise, you want a "glass lined" tank. That can handle the heat transitions. The procedure is to strip the outer metal jacket from the water heater, then strip the insulation from the water heater, until you are down to just the metal tank itself. Paint that black. Solar absorptive paint is available, but black paint made to coat metal will do.

You will need to build an insulated box. Sheet metal will work. For insulation, fiberglass works, but it deteriorates with moisture. Rock wool is better as it stands up better to moisture. Isocyanurate (polyisocyanurate) foam is the best insulation for solar collectors. Alternately, use an old refrigerator or chest freezer. Make sure the fridge is long enough for the water tank to fit inside it. Take the door off. Drill holes where pipes need to go through.

You will need to cover the front (where the door was) with glass or plastic. An old (or new) patio glass (as for sliding doors) will work. Those are fairly cheap if you buy a standard size.There are other glazing options, such as various polycarbonate products or kalwall. They work if you have them, but glass will last longer, assuming there are not a lot of rocks flying around your neighborhood. Beware that a lot of double pane windows have a "low e" coating (low emissivity) on them, but there are many different kinds of coatings used. Most low-e coatings are designed to block heat coming in rather than blocking the heat going out, and that such windows have an inside and an outside. Such low-e coatings are intended to reduce summer air conditioning demand, not maximize solar heat collected. If you buy new glass, specify a low-e coating that traps heat or use uncoated glazing. If you have to use scrap glass, then it will work, even if the efficiency is not maximized. Sometimes I have seen batch collectors built into a roofline.

In terms of considering what kind of solar water heater you want, the bottom line is latitude. In very warm places, it would be foolish to use anything but a batch collector because they are cheap, simple, and effective. In cooler climates, if you can afford it, a flat plate or vacuum tube system will dramatically outperform a batch collector. In the U.S., I live in Virginia. Certainly here, batch collectors are good for 8 or 9 of the warmer months, but fairly useless in winter. In central or south Florida, batch collectors are a "no brainer." Somewhere in between here and there is where you have to find the brains and build a more elaborate system.

Flat Plates and Vacuum Tubes Are Better in Cooler Climates

In temperate or cold climates, flat plate and vacuum tube hot water systems with pumped storage to a tank are far better than a batch collector. If you search for hot water collectors on the internet, the dominant technology is vacuum tube panels. My personal preference is for flat plate collectors. In theory, the vacuum tubes are a little more efficient in very cold weather than flat plates, but the vacuum tubes are also more fragile. Each collector unit has a number of vacuum tubes. The tubes can be replaced. Sometime a vacuum tube will shatter for no apparent reason.

Flat plates a more rugged. With a flat plate, there is a copper sheet with tubes through it behind a piece of glass, with the whole assembly mounted in an aluminum box. Quite a few companies have made these over the years, though the market has been reduced to very few at this point. Good quality flat plates for more tubes in the copper sheeting compared to cheaper flat plates, and foam (isocyanurate), not fiberglass, behind the copper sheeting. A flat plate collector spreads the fluid out thinner compared to a batch collector. Overall, a flat plate system is more efficient, and much more effective in cool weather than a batch collector. They are also extremely durable, lasting for decades. Our preferred company for new flat plates, as well as manufactured batch collectors, is AET in Florida (www.aetsolar.com). See images of the various collectors below.

For what follows, the reader may assume that is all applies to flat plate and/ or vacuum tube systems, though I will refer to such systems as “flat pate” for the sake of brevity. With a flat plate system in a cold climate, heated solar fluid (water or a water/ antifreeze mix) is pumped down to insulated storage tanks. There a few different ways to set up the tanks. The simplest system to build uses a solar storage tank with a built-in heat exchanger. These are not cheap. Another option is to use water heater tanks (electric water heaters) and an external heat exchanger. Another option is to make a tank from metal/ wood and foam, with a liner, and then put heat exchangers inside that. I have used all of these methods. For very large systems, the homemade tank is by far the cheapest. It requires more attention over time though.

Much of the east coast of the United States has rock substrate made up of granite. That means that well water on the east coast is often acidic and corrosive. That's not unhealthy. Distilled water is very "pure" but highly corrosive. Well water on the east coast is like distilled water. Urban water is treated with some ordinary substances like calcium and sodium, as well as some more esoteric chemicals, to make it less corrosive. This is relevant to solar hot water systems because well water can be corrosive to solar tanks. One has to consider this when looking into purchasing expensive solar hot water tanks. Stainless steel tanks are one expensive solution. Plastic non-pressurized tanks are another cheaper solution, but require more skill to design and install because you have to size and install your own heat exchanger (loops of copper or stainless tubing).

There are a number of different ways flat plate systems are set up. If you are off-grid like we are at LEF, then by far the smartest way to set up a flat plate system is as a "closed loop" that uses a small, DC circulator pump. The pump pumps antifreeze up into the panels where it is heated, and then down to the tanks. The heat from the anti-freeze is passed to the water in the storage tanks. The anti-freeze side of the system is a closed loop, meaning the same liquid stays in there and goes around and around that same loop for years and decades. The anti-freeze most people use in their cars is made of ethylene glycol and is very toxic. A less-toxic kind of anti-freeze is based on propylene glycol. It is a bit more expensive, but will not poison your pets or your children if they find it and consume some. Ethylene glycol poisons a certain number of pets every year. It tastes sweet, which is very bad for a poisonous substance. Propylene glycol can be obtained from several sources. We use automotive propylene antifreeze. It is more expensive than ethylene. One can also purchase solar fluid. That is often quite expensive. There is also “RV antifreeze” made with propylene, but I am not sure if that has corrosion inhibitors, which I think you want.

Another option is a “drainback” system that uses a stronger pump to pump water up to the collectors that then drains back to the storage tank. Yet another option is to use an AC pump with temperature sensors (thermistors) and a computerized controllers. I strongly prefer closed loop systems with a DC pump. That approach is much, much simpler. It's a direct drive system, like we use at LEF. You simply put a small PV panel (solar electric) up right next to your heat collecting panels. Sun comes out, warms up hot water panels, and generates solar electricity at the same time. That electricity starts the little pump turning that takes that heated glycol down to the tanks. Sun is up, pump runs. Sun goes down, pump quits. No temperature sensors, no thermostats, no computers. Very simple system.

There is one other tweak I have found on these closed loop systems that helps. Simply put a 50 pound pressure release on the closed loop side and push the operating pressure up to 25 pounds or so. Such a system will run for decades with no maintenance, no intervention at all on your part. Thirty years of hot water with no further work after you build it. Nice.

Disaggregation

Another small tweak that makes a big difference in whether or not you get a hot shower is to *not* build one big system. The dominant design approach assumes that solar hot water systems will always just be a pre-heat for fossil fuel systems. That has lead to the approach that each solar hot water system should be one big system. Well, in the winter time, solar resources are reduced. There is less sunshine. You need about 110 degrees to get a good, hot shower. But if you only have a little bit of 110 degree water, and someone dumps that nice hot water washing dishes or washing clothes, then you are either using another energy form to heat your water, or taking a tepid and uncomfortable shower in January. I had not thought this through carefully when we built LEF, but I built 3 different systems. Sometimes, we are using tepid water in winter to wash dishes, and I still get to take a nice hot shower. We do have a wood fired heater as backup heat. But gas and electric systems work silently, a wood backup heater means you have to go build a fire. The wood means you think about it, and thus choose to minimize that effort. We only use our wood back system less than a dozen nights out of an entire year. Now that I have lived with a disaggregated, closed loop, flat plate system for years now, I love it. It's great. A hot shower any time I want it, and it's almost always purely solar.

Overall System Sizing

There are some good solar design manuals out there I am sure. There must be, right? Well, don't let them convince you to aggregate your panels, or try to install them for just yourself. As for sizing of a system relative to the number of people, for most people it's going to come down to money and diminishing returns. Our DC Microgrid is cheap. Super insulated buildings can be built pretty cheaply.

But a good solar hot water system in a cold climate is going to involve some metal and money. The only way to can do that on the cheap (read sustainably) is to have multiple users on the same system. A solar hot water system for two people in a cold climate is going to cost $5,000 - $10,000. *But that same system, with slight modification, can support 10 people.* Obviously, the price per capita plummets with more users. This is why we say renewable energy scales to a village.

With off grid systems, there are diminishing returns. A couple of panels, assuming something in the 3 foot by 7 foot size range (that's pretty common) would cover more than half the hot water needs of an ordinary home. As you get deeper into trying to cover more and more of your winter load, then you would need more and more hardware.

We have mediocre quality panels at LEF that were donated. We have a total of 8 panels for 10 people. Six of those are dedicated to household water (showers and bathing), with 2 dedicated to the kitchen. The household system is great. The kitchen could use another panel at least. Or better quality ones. Our systems are running at about .4 square foot of solar collector per gallon of hot water storage. A little more or less would be fine, but not a lot more or less.

Orientation of Panels

The highest efficiency of any solar collecting device is achieved when the energy collector is at 90 degrees to the incoming sunshine. As far as solar hot water is concerned, there is a massive surplus in the summer. There is no such surplus in the winter. In a temperate climate, collecting enough heat in the cold and cloudy days of winter is a challenge. If you live in tropical climate, do what you want, but anywhere else, you need to have your panels at 90 degrees to the winter sun, or close to it. In Central Virginia, our winter sun angle is near 30 degrees from the horizon. You hot water panels should be near 60 degrees from the horizon, facing south. You don't need to have them facing perfectly south. Fifteen degrees east or west of south will not cost you hugely in efficiency. Shading will. Solar electric panels are really debilitated by shade. Solar thermal systems are not much better. They need to be in *full sun.*

Pumps

The pumps that bring hot liquid down from flat plate collectors to the storage tanks are called circulator pumps. They are the same kind of pumps used in hot water boilers that heat houses and commercial buildings. For AC solar systems that use thermistor temperature sensors and a controller, the exact same pumps that are used on gas hot water systems (hydronic boilers) can be used. Drainback systems need stronger pumps to lift the liquid all the way to the top of the system.

With closed loop systems like we use at LEF, you have to imagine a big circle. The storage tanks and the pump are at the bottom of the circle. The collectors are at the top. The whole loop is filled with liquid. With a closed loop, the liquid falling down one side of the loop helps pull the liquid up the other side of the loop. That means a very small pump will work. We used to use a pump called El Sid. They are no longer in production, so we use pumps from U.S. Solar. Look for ‘El Sid Replacement.’

One has to set up a charging station on closed loop systems, and know how to use it. See illustrations.

Pipe and Insulation

How hot a set of solar pipes on a closed loop system might get under normal operation is a question of the ratio of panel size to storage tank size. As long as everything is working properly, you are unlikely to see 180 F in your solar loop pipes if you have decent storage. The newer plastics, polybutylene and cross linked polyethylene (quest and pex) can handle 180 F. CPVC (not PVC) can handle similar or slightly higher temperatures. On paper, plastic pipe could work in a solar hot water system, as long as the storage tank size is adequate. The problem is that a stalled solar hot water system can shoot up to 260 degree F in an hour or two. If you have an AC based solar system, then a power outage could cause the liquid in our solar loop to overheat. This heat will migrate upward. If there are any plastic pipes higher than the panels themselves, the pipes will melt. If the pump gets turned back on before that liquid cools off, then that hot liquid could get pumped downward and destroy plastic pipes anywhere in the system. That’s why we tend to stick with all metal (copper mostly) in our closed loop systems. I have never actually seen our DC circulator pumps fail, but one could imagine a scenario where hot liquid got pushed downward.

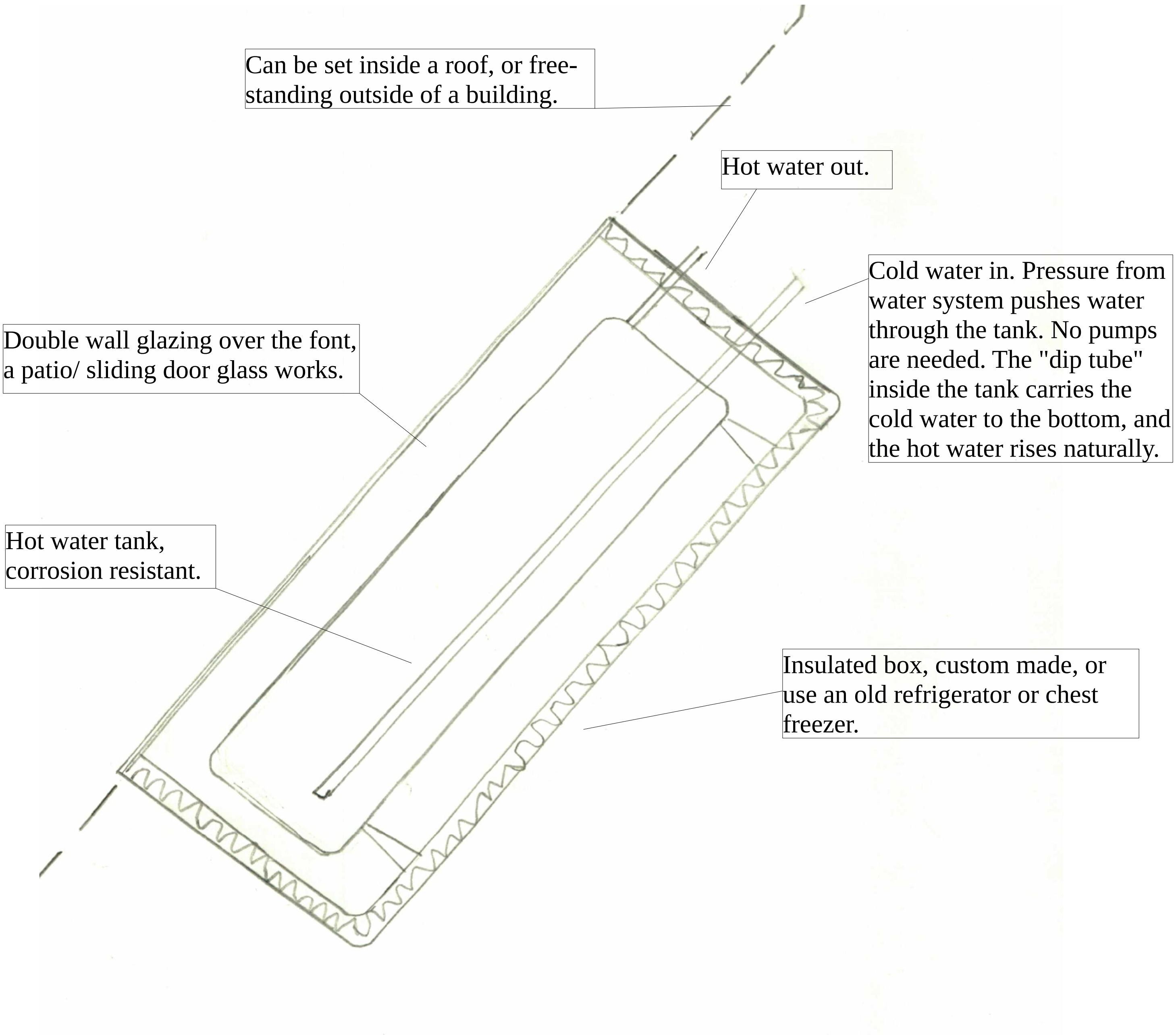
The failsafe method for piping is copper. It's easy to install once you know how, and it can handle lots and lots of heat. If you do use plastic (PEX or CPVC), I would suggest a metal header at the top of the system to handle the hottest liquid coming off the panels.

Beware, if you are going to do closed loop, you have to be a good plumber. A leaky closed loop will shut down if an air bubble forms at the top of the loop. If it leaks, it will not work. The closed loop side of the system has to be 100% leak free.

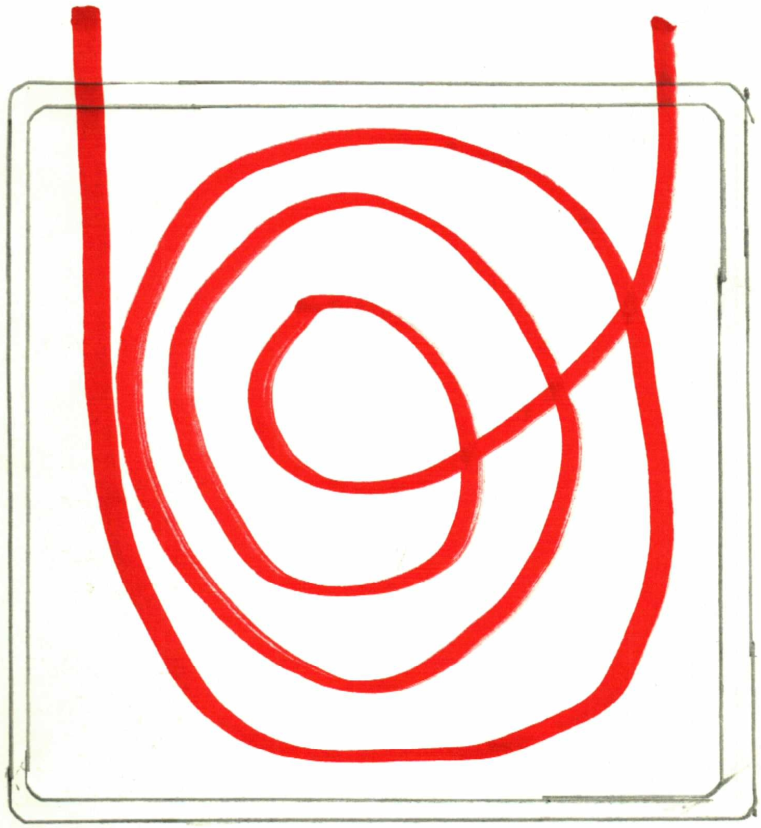
Just like you need pipe that can handle high temperatures, you need pipe insulation that can handle high temperatures. It does not work to buy the cheap foam pipe insulation that is commonly available in hardware and building supply stores. That will not stand up to the high temperatures you can get on flat plate solar hot water systems. There are a number of high temperature pipe insulation options. The problem is that a number of them are quite expensive. Indoor insulation is easier. Fiberglass can be used. For outdoor insulation, we have used a number of products. The least expensive decent quality insulation we have found that has a high enough temperature tolerance and is suitable for outdoor use is elastomeric foam pipe insulation. Check prices through different suppliers.

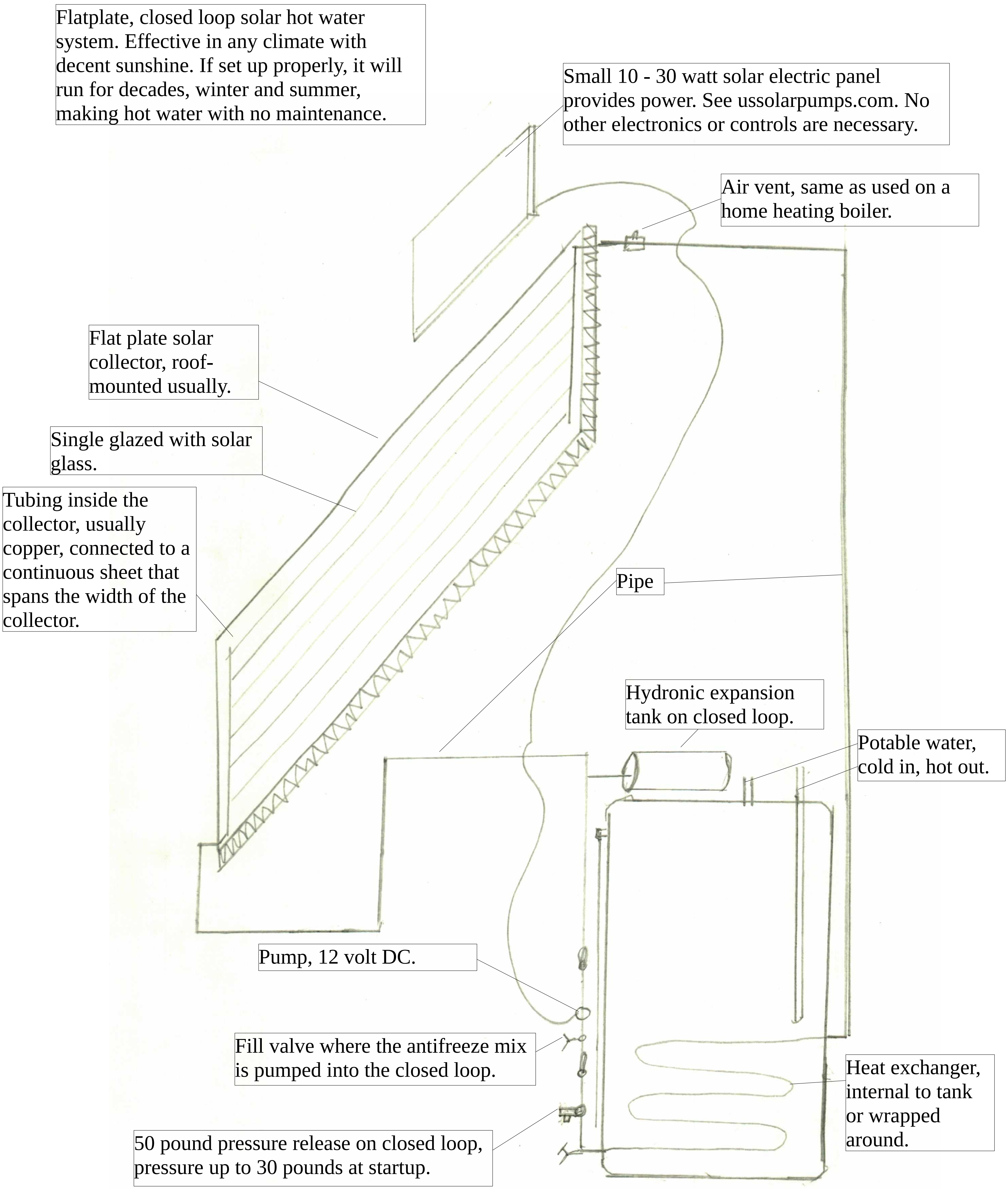
We have a wood backup heater for our hot water system, but we rarely use it. It was made by D&S Machine in Gordonville PA. I find it quite comforting that each and every day, with no effort at all on my part, our little solar pumps make hot water, year round, and with no ongoing energy costs at all. Night after night through the cold of winter, I take hot showers or soak in a tub of hot, solar pumped, solar heated water and marvel at all my friends who tell me my life represents a deprivation that most people are not willing to endure. That's a defense mechanism, I have come to understand. It relieves their guilt or discomfort with living the consumer life.

Solar batch collector, by far the cheapest, easiest way to heat water, but only effective in moderately warm climates. They work in Virginia for about 8 months out of the year.

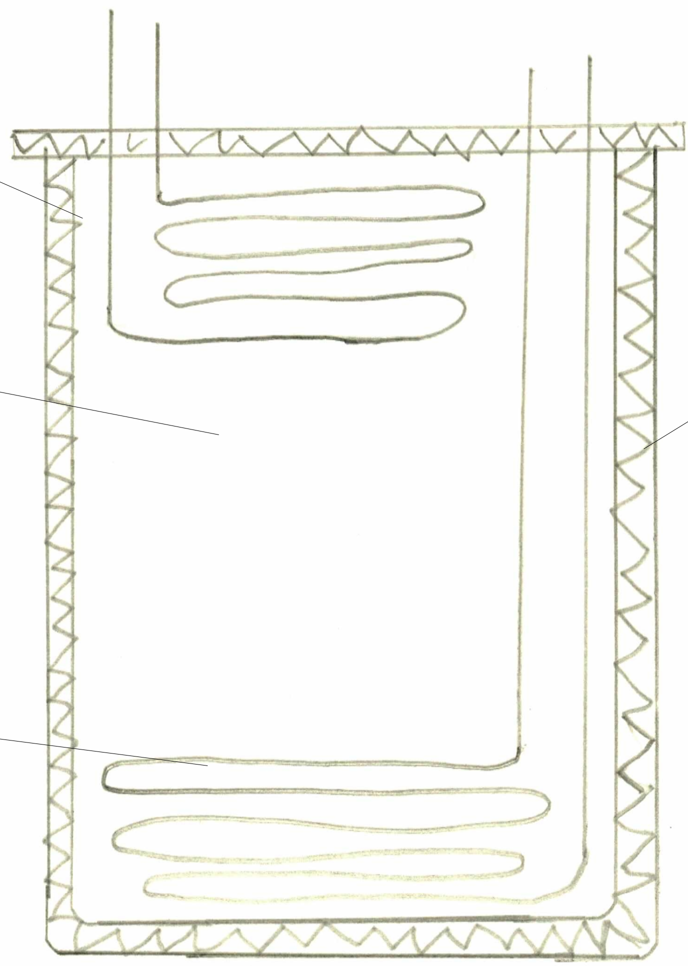


This is a coil of pipe inside of a box with glazing over the front, turned to face the sun. I have seen numerous people try to make homemade solar water heaters this way. It will not work. Only the pint or so of hot water in the pipe will be heated.




Flatplate, closed loop solar hot water system. Effective in any climate with decent sunshine. If set up properly, it will run for decades, winter and summer, making hot water with no maintenance.
Small 10 - 30 watt solar electric panel provides power. See ussolarpumps.com. No other electronics or controls are necessary.
Air vent, same as used on a home heating boiler.
Flat plate solar collector, roof-mounted usually.
Single glazed with solar glass.
Tubing inside the collector, usually copper, connected to a continuous sheet that spans the width of the collector.
Pipe
Hydronic expansion tank on closed loop.
Potable water, cold in, hot out.
Pump, 12 volt DC.
Fill valve where the antifreeze mix is pumped into the closed loop.
Heat exchanger, internal to tank or wrapped around.
50 pound pressure release on closed loop, pressure up to 30 pounds at startup.

Cheaper solar hot water storage tank setup, useful for larger systems especially. Tank is non-pressurized, plastic, thus much cheaper. This system is plenty durable.



Resources:
Solar hot water pumps, closed loop only, see ussolarpumps.com
Other solar hot water components, including very high quality stainless water tanks
http://www.aetsolar.com/

Chapter 5 -- A Simplified Way to Understand Volts, Amps, and Watts

Basic Electrical Principles

Electricity is an extremely complex phenomena. Any metaphor that attempts to explain all of its manifestations will fail at some point. That being said, general household and PV electrical systems can be understood employing a metaphor of pressurized water. If you imagine a pipe carrying pressurized water toward a turbine (a waterwheel used to do work), the pressure represents voltage (V), and the volume represents amperage (A). If you think of how much work the turbine can do, it could do the same amount of work with either higher pressure and lower volume, or higher volume and lower pressure. That work is represented by watts, which is volts X (times) amps. 1 volt X 10 amps = 10 watts = 10 volts X 1 amp.

This equation is true for AC or DC power. The size of the pipe (wire) will restrict the volume (amps) that can easily flow through the wire. Try to push too much volume through too small of a wire, and the wire gets got. That is inefficient, and possibly dangerous. It is easier to move more power through a smaller (cheaper) wire with higher voltage (pressure). That is one reason we put PV panels in series to generate 90 or 180 volts DC to run industrial motors. Our low voltage (12 volt) system only runs electronics (smart phones and computers) and lighting, both of which use little electricity compared to industrial motors.

As our metaphorical water moves through a pipe, the friction of the water rubbing on the inside of the pipe, and the resistance to flow of the turbine itself, are called just that -- resistance. Material that passes electricity easily, like copper wire, has low resistance. Resistance causes some of the energy in the electricity to be converted to heat. An incandescent light bulb (the old fashioned kind) has a lot of resistance. That resistance limits the amount of electricity that can pass through the bulb, and converts most of the energy passing through to heat (about 95%) and the remaining 5% is turned into light. More resistance means less energy will pass through an electrical device. Higher voltage means more pressure, which will force more energy through an electrical device. Each device is designed to handle a certain amount of energy. Voltage higher than a particular device is designed to handle would force through too much energy, and damage a device.

Electrical Units (Metaphorical)

Voltage = V= Pressure
Amperage = A = Volume
Resistance = Resistance to flow, restricts the amount of energy that can flow through a wire or device, and causes electricity to be converted to heat/ and or mechanical power. The symbol for resistance is a little horseshoe, called ohms, like this Ω. Sometime R is used as well.
Watt-Hour (or kilowatt-hour, kwh) = the amount of work that can be done in an hour. This is what the power company measures with the meter outside your house.
Watts = Volts X Amps = Work that can be done. Watts, or kilowatts, can be mathematically calculated as horsepower as well, useful for understanding what motors you can run with a particular power source.
Volts = Amps x Resistance = the equation that relates resistance to voltage and amperage. Note, this equation is normally expressed as V=IR where I = amps. Not sure why.

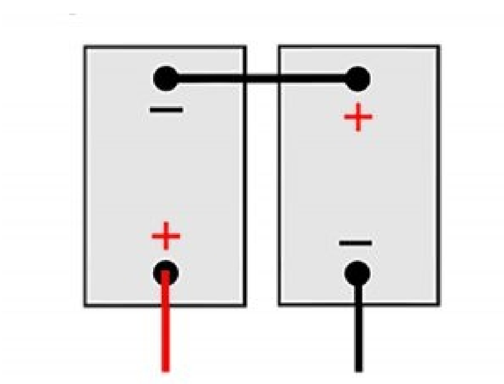
Series and Parallel Circuits

Understanding series and parallel circuits (illustrated below) is important. The terms series and parallel apply to both energy production circuits (several solar panels) or to energy using circuits (the wiring in a house).

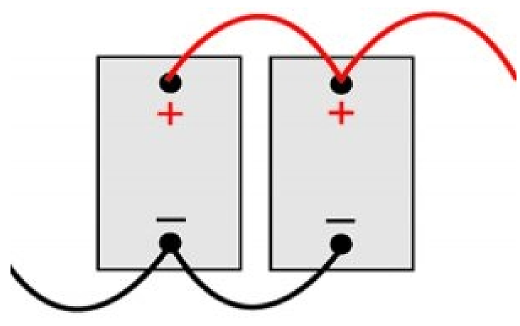
In an energy producing circuit, a series circuit adds voltage while amperage remains constant. Our main power supply at LEF is a set of six 30 volt PV panels in series. 6 X 30 = 180 volts. Each panel has about 8 amps output, and so does the whole series circuit when the circuit is in series. The total power output is 180 volts X 8 amps = 1440 watts. If you put all six panels in parallel, you would have 30 volts on the output, but 6 x 8 amps for 48 amps. That would mean you would need a heavy, expensive wire, and the voltage (because of the low 'pressure') would not travel as well down the wires over longer distances. But with either series our parallel, the total output is the same. Mathematically, 180V X 8 A = 1440 Watts = 30V X 48 A.

We also power some irrigation pumps with 24 V motors. In that case, we use two 30 V panels in parallel. In a parallel circuit, the voltage remains the same while the amperage adds up. A 24 V DC motor is perfectly happy running at 30 V. If we put the panels in series and tried to run 24 V motors at 60 V, that would be a pretty high voltage for a 24 volt motor. Whether your panels are hooked in series or in parallel, the wattage (total power output) remains constant.

A normal house is wired as a set of parallel circuits. In a house, every device, large and small, has the same voltage available (120 V AC in the U.S.) because the whole house is set up with parallel circuits.



Series Circuit, Adds Voltage, Amperage Stays the Same, Total Power Output Remains the Same



Parallel Circuit, Adds Amperage, Voltage Stays the Same, Total Power Output Remains the Same

With our voltage = pressure metaphor, electricity always pushes its way into the low pressure/ low voltage parts of a circuit and kind of just puddles there. This is true in both parallel and series circuits. Back in the old days, PV panels had a monolithic interior design. A single bird dropping would create a low-voltage spot. All of the electricity from the PV panel would flow to that spot and create heat. The output of the panel would drop dramatically. Modern PV panels are better, but ***even a small amount of shading dramatically reduces the power output of PV panel. You can put your hand in front of a large PV panel, and even though you may only cover 10% of the panel, you may reduce the output 50% or more.***

Because of the tendency of electricity to "puddle," you cannot use different kinds of batteries in the same circuit. If you have a flashlight that uses several batteries, and you mix strong batteries with a weak one, as soon as you turn on the flashlight, most of the electricity goes from the good batteries towards the low-voltage puddle in the weak battery. Your batteries die quickly and your light does not work very well. The same is true of large batteries. You cannot mix different sizes or kinds of batteries, or old and new batteries, effectively. Nickel iron batteries (NiFe) are an exception to some degree, as they maintain their strength for a long, long time. Even then, one would want to pay close attention to setting up a circuit mixing older and new NiFe batteries.

The puddling effect of electricity also means that it is not wise to mix different kinds of PV panels in a power production circuit. It may work, but it will not be efficient. Different panels will have different output voltages, and the electrical output will puddle in the weaker panels.

Tilt of PV Panels

Our winter sun angle at this latitude (Virginia) is near 30 degrees, with the summer sun angle near 90 degrees to the ground. For solar electric photovoltaic (PV) panels, you want year-round energy production. Sometimes people tilt them seasonally. If you want to do that, you will need an adjustable rack. If you want a stationary rack, then a good tilt for all-around performance is about 30 degrees from horizontal at our latitude. That is halfway between the winter and summer optimal angles. Adjust accordingly. You want them pointed south, but it does not need to be a perfect south. A bit east or west of south (15 degrees or less) does little harm efficiency wise. If you want power earlier or later in the day, you can tilt the panels east or west. Make sure they are bolted down well enough so the wind will not damage them. Beware that optimal solar hot water panel angles are very different from optimal PV panel angles.

Resistance and Direct Drive PV

If you think of resistance as a valve in a pipe (wire) carrying the metaphorical water (electricity), if the valve is mostly closed, then not much water (electricity) makes it through. If the valve is more open (less resistance), more water (electricity) will flow through. Another way to say that, larger, more powerful electrical appliances use more electricity because they have less internal resistance. With grid power, it is as if your pipe (wire) is connected to a large lake. The limitation is the opening of the valve (resistance), not the supply of water (electricity). If you were to graph the relationship of resistance and energy use where one axis is decreasing resistance and the other is increasing energy use, then the graph would look like a line going up in a linear and persistent fashion.

With battery-based DC electricity, the wire sizing and circuit planning are similar to AC in that batteries have a large ampacity. Just like with AC, you have a large supply of amperage (volume). Wires must be large enough to handle the expected loads. Circuit breakers and fuses are used to make sure the wires do not overheat. Other than that, one can assume that lowering resistance will increase energy use up to the maximum point that the equipment (wires etc) can handle.

With direct drive PV, this all changes, at least in some ways. With a direct drive circuit, you don’t have a big battery or “lake” of electricity, you have a distinctly limited supply. That means the line of energy use cannot simply go up the way it does on a graph of AC electricity use. With a direct drive circuit, electricity flow increases as resistance decreases, but only up to an optimal point. It is a bit counter-intuitive, but with a direct drive circuit, if resistance continues to fall beyond a certain optimal point, energy use (efficiency) starts to fall. Thus if we use the same graph we mentioned for AC power, where one axis is resistance and the other is total energy (watts), the power output a direct drive circuit powered by PV panels is going to look like a bell curve, not an ever increasing line. Too much or too little resistance and you start to slide off one side or the other of the bell curve.

Maximum Power Point

If we look at a particular DC load such as an Insulated Solar Electric Cooker (we will talk about those later), and we assume optimal, static conditions, it is easy to calculate the optimal resistance and the peak potential energy output. Let's do that for LEF's high voltage circuit. Let's say we want to build an ISEC that will use every single watt being produced by our 180 volt, 8 amp, 1400 watt solar rack. We simply solve for V=AR (V=IR). 180=8R, so R = 180/8. R=22.5 ohms. That would be the resistance needed to capture 1400 watts.

One should also note that any such 1400 watt burner would need to be made to actually handle 1400 watts. That simply means the wire sizes must be adequate. (A heating element is simply an encased wire made of nickel chromium. That is a metal that has a high resistance, thus it converts electricity into heat, instead of letting the electricity travel through it easily, as does other metals like copper.)

The counter-intuitive part of direct drive is that with our 1400 watts circuit, any resistance that is more or less than 22.5 ohms is going to mean less efficient use of the available energy. The same is true for any direct drive circuit. Any resistance above or below the optimal resistance is going to reduce energy capture.

The tricky part is that the total power available changes with a direct drive PV circuit as sunlight intensity increases and decreases. Imagine a partly cloudy day where sunlight is constantly increasing and decreasing. The optimal resistance would be constantly increasing and decreasing. The peak of the bell curve is always moving. This drives some engineers crazy. It has led to some unflattering comments being directed at the D3M from electrical engineers. You don't need to sweat too much over it. D3M works great, regardless of power output swings. It does help to understand what is happening though.

The point at which resistance and PV power supply are optimally matched is called the Maximum Power Point. A device which measures incoming power and load and changes the voltage and amperage to maintain optimal efficiency is called a Maximum Power Point Tracker, or MPPT. In theory, one could use one or many MPPT devices on a direct drive circuits to improve efficiency. We use some MPPT devices at LEF. Our well pump, for instance, is an expensive Grundfos pump with its own MPPT driving the pump motor. Many of the Chinese made pumps also have MPPT devices at this point. A well pump is the most critical device on our farm. I am certainly happy to have it operating at peak efficiency, particularly on cloudy days when we trying to get as much water as we can with a reduced energy supply. That said, I have no interest in putting an MPPT device on every tool and appliance we have at LEF. There is just no need for it. Adding that much electronic crap to our system is not desirable.

We actually do a great deal of manual 'MPPT' tracking by simply turning devices on and off as we need them. If I have a project that I know need more energy, I plan for when I do it. If I have a small project running a tool in the shop, sometimes I might turn off another load so I can finish my project. Managing a direct drive system takes some knowledge of what's going on with the system, but the system itself teaches you fairly quickly.

The one case in which 'manual MPPT' need a bit of help is with the cookers (ISECs). There it helps to actually do some math. We have multiple power levels in our cookers. On our largest cookers, we have two or three burners. We have a switch that allows us to run one burner at a time, or to put two burners in series. The series arrangement increases resistance. The counter-intuitive part is that, in partial sun, you sometimes get more heat (more watts) with two burners in series (more resistance) than with one burner. We are following the peak of the bell curve as it moves. We have analog voltmeters on the cookers so we can pay some attention to the results of our actions.

Chapter 6 -- Direct Drive Provides a Lifetime Energy Supply With Near Zero Operational Costs

At Living Energy Farm, we developed a means of utilizing solar energy that we call Direct Drive DC Microgrid, or D3M for short. D3M has many advantages, but it is important to understand that D3M comes after cooperative use, conservation/ good insulation, and good thermal design. As many times as I say that, I often here other people who talk about LEF saying things like “they have a really cool DC electrical system.” Thanks for the compliment, but replacing AC power with DC power in the current economy is of no real advantage. A one-half horsepower DC motor running a tumble dryer will do more or less the same thing as a one-half horsepower AC motor running a tumble dryer. The point is to hang up your clothes on a clothesline, not swap the motor. And then proceed to hold the powerful people and corporations responsible for lying to the public about climate change and industrial “renewable” energy.

Grid power is alternating current, or AC. We are interested in direct current (DC) electricity for a few reasons. Solar photovoltaic panels (PV) put out DC electricity. Batteries are also DC. The advantages D3M are compelling;

1) The D3M system at LEF allows for a modern lifestyle with dramatically lower energy input. Our D3M consists of 250 watts (.25kW) of PV panels and 200 watt hours (.2kWh) of battery storage per person. Our microgrid design **requires 8% as many PV panels and 2% as much battery capacity** as is needed to provide residential energy services with conventional solar and storage systems that supply AC.
2) A "normal" American home uses tens or hundreds of dollars worth of energy every month. We are energy self sufficient with *no energy bills*.
3) Normal off-grid systems for an ordinary house are expensive in terms of battery and equipment replacement costs. There is a wide range depending on the size of the system, but $2,000 per year is pretty normal. The annual cost of our DC Microgrid is hard to calculate because the equipment lasts so long, but $50 per year is my best estimate for supplying the domestic energy needs of 10 people.
4) Living in a rural area, our neighbors loose power in thunderstorms, snowstorms, and other weather events, sometimes for days at a time. In fifteen years, we have never had a power outage. That's because:
5) All other energy systems are linear. All energy comes from the grid or a central battery bank. Our D3M is actually 8 different systems, depending on how you count. Any problem in one system does not challenge the viability of the whole system. Unless you turn them off, our lights never go out.
6) Most off-grid systems need a backup generator. We do not.
7) Our DC electrical system pumps solar hot air from collectors to heat the house. That covers about 95% of our heating demand. The remainder is covered by wood from a small wood stove. We use two or three wheelbarrow loads of wood *per year*.

How to Build D3M -- Reader Assumes Risk

The reader, in pursuing this document further, does hereby fully indemnify and hold harmless the author from any harm to persons and/ or property that might result from any attempts of the reader to implement any ideas or practices explained in this document. You are pursuing these practices at your own risk.

In electrical code, anything below 48 volts is considered "low voltage," and is not considered to present much of a hazard of shock or electrocution. Certainly, a single car battery at 12 volts DC or a single solar photovoltaic (PV) panel, usually at 35 volts DC or less, does not pose a shock hazard. However, if you tie two PV panels in series (we will explain that shortly), you could have 60+ volts.

That voltage poses a risk of electrical shock. In my community, we use a lot of 180 volt DC equipment. A lot of grid-tied PV equipment runs at even higher voltage. Voltages that high poses a risk of shock or electrocution. (My sister's ex-husband was killed by a 48 volt stage lighting wire. Under specific circumstances, even modest voltages can be dangerous.) If you do not have experience assembling higher voltage systems, get help from more experienced electricians. Always make sure the power source is disconnected or turned off before you work on any electrical system. Buy proper test equipment. Volt meters can usually be found for $20 or less at any hardware store. Get one and learn how to use it. Beware than any meter that sits around for a long time may suffer from a weak battery. A meter with a weak battery may give erroneous and unpredictable readings. Always test your meter against a live circuit before you test a circuit that you presume to be deactivated.

All electrical wiring coming from any source needs to be installed by someone who has the knowledge and experience to do it safely. It is absolutely critical that wiring from any battery source have appropriate circuit breakers (preferred) and/ or fuses. All batteries have a high ampacity -- the ability to put out high amperage for a short period of. If the wires are too small, this high amperage can cause heating and start a fire

High voltage DC wiring is very similar to household AC wiring. Wire sizing is a complex undertaking. There are wire size calculators online, but interpreting them appropriately requires some experience with the terms used to describe the wiring and the circumstances under which it is used.

Choosing Voltage for D3M

Most modern solar electric PV panels are being manufactured for the "grid-tie" market. That just means that most modern panels have higher voltages than older panels. That's fine, in fact desirable, from the perspective of using them for direct drive. Look at the Vmp (voltage maximum power) on the panels that you have or are thinking about getting. In the context of direct drive, you would want a target voltage of either 90 - 120 volts or 180 volts. A bit higher or lower is fine. A 90 volt setup would likely involve 3 panels in series, possibly in parallel with 3 more panels in series. A 180 volt setup would likely involve 6 panels in series. Almost all household appliances (not major appliances like heat pumps or heaters) are in the range of a couple hundred watts up to 1500 watts or so. Certainly the 1400 watt system we have at LEF has served us well. An minimalist daylight drive system at half that wattage would work for many motors.

A nominal 90 volt PV rack would allow you to run 90 volt industrial brush motors. These are available from many industrial suppliers. Used motors are available on craigslist or ebay. A 90 volt system (or up to 120 volt DC) would run *some* household appliances rated for 120 volts AC. The standard for AC electricity in Europe and Asia is 220 volt AC. *Some* of those appliances will run with PV power at 180 - 220 volts DC. It is also possible to use a switch and make a solar PV rack put out two different voltages. We do that at LEF, but I don't recommend it. The simpler approach is that if you live in the U.S., set up a nominal 90 - 120 volt DC system. If you live in a place that has 220 volt appliances, set up a 180 - 220 volt DC system.

Surge Arrestors and Grounding

If you live in an area with thunderstorms, we strongly recommend a surge arrestor. Cheap but adequate ones are $50. Higher quality (probably more reliable) ones are $100. It is well worth the investment to spend that money to protect more expensive equipment like a refrigerator. PV panels generally have to be up high to get good sun. Being up the air like that, they tend to attract surges in a thunderstorm. These electrical surges are like mini-lightening strikes. It's very common. The surge arrestors work pretty well. It is also a very good idea to attach a ground wire to the metal frame of the PV panels and take that down to a ground rod, especially on larger installations.

Powering AC Equipment with DC

A DC motor will do the same work as an AC motor. The easiest way to set up equipment, particularly shop equipment, is to find older belt-driven tools. Unfortunately, more and more modern equipment and appliances are direct coupled, meaning the motor is bolted directly to the tool or appliance with no belt. That makes motor substitution more difficult.

Let's say you want a bench grinder or a grain grinder. If you can find an older one with a belt, then motor substitution is super easy. Look at the label on the AC motor. The important information is:

1) **HP**, which stands for horsepower. You have some flexibility. If your tool has a 3/4 hp motor, you could use a 1/2 or a 1 hp motor. The 1/2 hp motor will give you less power, but will run a little better in very low power situations (in cloudy weather). The 1 hp motor will give you more power, but may not run as well at very low power if you only have a 1 hp PV power supply. Using the same hp on your DC motor as the AC motor is ideal.
2) **RPM**, which stands for rounds per minute, or simply speed. Most AC motors are 1700 - 1800 rpm, or 3600 rpm. DC brush motors are easily available in these speeds. DC motor speed is fairly easy to adjust. In industry, DC motors have been used in countless applications as the simplest way to have an adjustable speed motor. But having a motor that has the same approximate speed of the one you want to replace is easiest.
3) **FR**, or NEMA (National Electrical Manufacturers Association) Frame, tells you the exact physical layout of the motor. It tells you the shaft size, and the size and location of the mounting bolts. The common FR sizes on shop and household machines are FR 48, FR 56, FR 56C, like that. That tells you what the drive side of the motor looks like. The FR size does not indicate the total length of the motor. If you happen to have a machine where the total motor length matters (none of ours fit that bill), then you would have to consider that. DC motors are sometimes longer than AC motors. We have on occasion had to modify food processing equipment to accommodate the extra length of DC motors.
4) **Duty**, you really want continuous, or CONT. Some junky equipment is only made to run intermittently.
5) **A or Amp**, Amperage on a motor is essentially redundant with HP. But if you are trying to run other motors (like household appliances) that only give you a wattage, then you can figure out the amperage needed by an appliance with the equation volts X amps = watts. So if you have a 1200 watt appliance made to run at 120 volts, you would need 1200 watts/ 120 volt = 10 amps. To run said appliance, you would want something close to 120 volts and 10 amps. A bit less is fine for amperage. A bit more or less is fine on voltage, but not a lot more or less for appliances with universal motors (see below).

Different Kinds of Electric Motors

Hundreds of different kinds of motors have been designed and built over many years. For our purposes, we are going to group them together in a few basic categories. Beware, some motors do not fit in these categories.

Permanent magnet DC motors (PMDC) are the most common motors we use with D3M. They are cheap and widely available. They tolerate huge voltage changes with no damage to the motor. They reverse direction simply by reversing polarity.

PMDC motors are also very simple. Any child who has ever played with magnets knows that two magnets will push away from each other if the same polarity is put in proximity on each magnet (positive near positive, or negative near negative). PMDC motors have a permanent iron magnet and electromagnets that is activated as one passes near the other, thus pushing away from each other. The electromagnets are connected to the shaft and thus cause it to turn.

PMDC motors are “brush motors” in that they use a brush rubbing against a commutator that carries the electricity to the coil (the electromagnet). The brushes on brush motors need to be replaced. With good quality industrial PMDC motors, you might need to replace the brushes if they run a lot. For motors that run very little (like a drill press or bench grinder), you would probably never replace the brushes. If you have a need for a motor that is going to run all day every day, you could consider a brushless motor, but they are a lot more expensive. Also, small brush motors are far less durable than the larger industrial brush motors. If you want a household DC fan, I would suggest you go with brushless. It’s a small motor that runs many hours. If you don’t replace the brushes on a brush motor when they get very worn, it damages the commutator. That is the death of most small brush motors.

Used higher quality American PMDC motors (Baldor and Leeson) are available on online auction sites. There are other kinds of DC motors including “shunt wound” and “stepper” motors. You don’t want those. Leeson does a better job labeling their motors so you know what they are. It is a good idea to standardize to one or two brands. The brushes within a brand are more likely to be interchangeable on different sized motors. The cheaper Chinese made brush motors seem to mostly work fine, though they are clearly not as good quality wise as American motors.

Brushless DC motors are increasingly common in particular applications such as electric bikes, electric scooters, and battery tools. Larger industrial brushless motors are hard to find and very expensive. (Sun Pumps has them.) Brushless motors have an electronic circuit that effectively replaces the brushes. They run for longer than brush motors, but once they wear out, they are not repairable for the most part.

For D3M, one should be aware that some brushless motors tolerate wide voltage variation, and others do not. If you are buying a new device with a brushless motor, the literature with the device should tell you the limits of voltage change. That is the case with water pumps. Note that pump controllers (that’s the electronic circuit) measure the voltage before they try to turn on the pump. The “voltage” in this case the VOC (voltage open circuit) on the PV panel, not VMP (voltage maximum power). VMP is always lower than VOC. If, for instance, your pump controller says that 72 volts is the maximum, then you cannot put two PV panels with a VOC of 40 in series to power that controller.

Scooter motors are one source of cheap brushless motors. Some scooter motors tolerate wide voltage changes, some do not. You have to simply find the brand that works for you. Beware that brushless motors are always more expensive and more complex than a similar brush motor, but many people selling devices with brush motors do not identify them as such. You have to assume that if the literature does not say “brushless,” then it very likely has brushes.

While PMDC motors are fine for most farm, kitchen, and shop tools, there are a few applications brushless motors are desirable. One is **submersible well pumps**. Because these pumps are hard to remove, brushless is better, but not cheap. Another application where brushless is better is with **small household fans**. These run long hours, and small brush motors don’t hold up so well. To my knowledge, there are none on the market other than ones we have brought in and market though **livingenergylights.com**. That website also has some Ningbo Cheer pumps (brushless multi-stage surface booster pumps). **Circulator pumps** should be brushless. For us, these are used for solar hot water systems, though they are also used in hydronic boilers. For solar hot water systems (see that chapter), see ussolarpumps.com.

Universal motors are more a class of brush motor rather than a very specific configuration of motor. In a normal house, any small appliance that you can pick up and carry around will be a universal motor. These motors also use the principle of magnets pushing against each other, but they use multiple electromagnets, not permanent magnets. This makes universal motors small, lightweight, and powerful. Any power tool with a cord, blender, or vacuum cleaner will likely have a universal motor, and 90% of these will run with DC power. To do so, you will need to match the approximate voltage and power requirements of the device in hand. We often run 120 volt household appliances and tools at 90 - 120 volts DC. That works great, but a couple of cautions are in order. Not all carry-able appliances will work. About 10% of such motors have peculiar multi-speed designs that are not suited to DC. Also, universal motors do not tolerate the extreme voltage and power variations that PMDC motors tolerate. On a cloudy day, we can often run one or two PMDC motors at LEF, even if the power supply is at 10% of full power. Universal motors will not work at these low power levels.

Induction motors are found on most large household appliances (such as washing machines) or normal AC shop tools. These motors cannot run on DC power.

Upgraded Switches

Upgraded switches are needed to run DC appliances and tools. All switches arc at least a bit as they open or close. The pulse of AC circuits breaks the arc as a switch opens and prevents a sustained arc from forming. The constant electrical pressure of a DC circuit does not break the arc. Thus, with DC power, a sustained hot arc can damage a switch or even start a fire. There are several considerations and solutions. Beware, you proceed at your own risk here.

There are **DC rated switches** and you can use those, though they are expensive. AC toggle switches are very light, including "specification grade" switches that are supposed to be heavier than normal toggle switches. **Knife switches** are much heavier. Most modern **disconnect switches** are a knife switch configuration. They hold up fine to DC electricity. Beware that old or very cheap knife switches might not be spring loaded. Without the spring, they can be almost engaged or almost disengaged, thus leaving a gap between contacts that arcs. We have used such switches in the past. We do not any more, at least not on 90 or 180 volt circuits. Higher voltage and higher power leads to more arcing. Arcing is not an issue on low power 12 or 14 volt circuits.

Drum switches are another good answer. They have contacts that come together in a similar fashion to toggle switches, but the contacts are much heavier. All modern drum switches are spring loaded, which you want.

Another solution to the arcing problem is **snubbers.** There a number of different kinds of snubbers, and they are used in different applications. The arc that forms as a switch opens or closes concerns us from the perspective or generating heat or damaging the switch. It concerns audiophiles and other electronics designers because electrical arcs generate noise that can interfere with audio systems, radios, or other electronics. We use simple propylene film capacitors as snubbers (.1 to 1 MF, or micro-farads). The capacitor is short circuited across the terminals of the switch, and in layman's terms, absorbs the arc. We use a lot of capacitor snubbers this point. Beware that, though the capacitors are durable, they can fail. One needs to consider how a particular device will behave if the snubber fails.

Running Your DC Shop Tools from a Grid Power or a Generator

It is also worth mentioning that we occasionally employ a **bridge rectifier.** That is a very simple device that converts AC to DC, or something very close to DC (close enough that a DC motor can't tell the difference). A diode is a device that only lets electricity travel in one direction. While AC power is represented as a sine wave, it is more like a sound wave that pulses. If you put a diode in an AC circuit, it lets half of the AC pulse through, and blocks the reversing half of the pulse. That is kind of like DC power. A bridge rectifier is a slightly more sophisticated version that uses several diodes. The sum cost of the parts is only a few dollars. Bridge rectifiers come in handy when you want to run a PMDC motor from AC grid power or an AC generator. Let's say a friend wants to borrow one of you tools that you have set up with a PMDC motor, or you need to run one of your PMDC powered tools on an emergency basis with a generator. Either way, you just plug in the bridge rectifier, and you are in business. The AC power is converted to something close enough to DC that your tools will work just fine.

Why Not Just Use an Inverter You Dumbass?

If the reader will pardon the expletives, we deal with lots of folks who think they have a better answer. Certainly, D3M is an outlier among energy systems. Normal off-grid systems always use larger batteries and inverters. (An inverter is a device the converts DC to AC, which is far more complex than converting AC to DC.) That only works for people who can afford the batteries, and then afford to replace the batteries. Lots of people suggest hybrid systems using both AC and DC, but we don't recommend it.

Certainly, inverters are convenient because you can use all of your existing AC tools and appliances powered from a DC source. Almost everyone gets suckered into going down that path without realizing the weaknesses of that approach. Lets say I need to accomplish some task, whether its running the washing machine, a grain grinder, or some tool in my shop. If I am running an inverter, first of all the original expense is much higher. Then, when the batteries weaken, the tool turns off. Certainly, with D3M, you have to work around cloudy weather. And you have to find or convert your tools to run on DC. With D3M, you have a fluctuating power supply that is usually sufficient to do what you want. With AC, the machine turns off if the power supply weakens. With DC, the device just slows down a bit, which is a much better situation. With an inverter, you set yourself up for being shut down completely.

Ultimately, the answer you get depends on the question you ask. Our mission at LEF is to try to make renewable energy systems accessible to low income people. D3M is a great tool toward that end provided there is some investment made in a village level D3M system. The inverter approach is a complete dead end in terms of helping low income people gain greater access to renewable energy. Off grid systems with inverters cost about ten times as much as grid power per delivered kilowatt-hour. The cost of D3M is much, much cheaper. Over time, the cost difference is monumental.

Adjusting Speed

A lot of DC motors have been used historically in industry, both in very large machines and in variable speed machines. A DC motor maintains full torque over full rotation, which means large DC motors make it possible to avoid massive transmissions in large mining or railroad engines. With any machine that needs to run at varying speeds, one can vary the speed to DC motors with rheostats, potentiometers, or pulse width modulation circuits. At LEF, we have not found the need to employ any of those devices. One can also use mechanical devices that vary speed. These are called torque converters, or continuous variable speed transmissions. Our lathe has one of the latter. Modern variable frequency drive motors have replaced DC motors in most variable speed applications, though the PMDC motors are much simpler.

For any belt or chain driven machine, you can change the speed by simply changing the ratio of the pulleys or sprockets. It's a simple ratio. If you have a 2 inch pulley on the 1700 rpm motor and it's driving a 4 inch pulley on the other end (such as a grain grinder), then the grinder will turn at 850 rpm (1700 / 2).

Beware Heavily Loaded Motors

We have found that with motors that are not running a heavy load, like blowers and pumps, it's fine to let them run as the direct drive voltage swings all over. *This is not true for heavily loaded motors such as on a grain grinder or compressor.* With a blower, as the blower slows down, there is very little resistance. With a grain grinder or compressor, if you try to run it at very low voltage, it will stall. If it stalls for a few seconds, then that's not a problem. But if you left that motor sit stalled for a longer period of time, you could generate considerable heat in the motor, wiring, and switches. If you are using anything other than a heavy switch, that will be the first thing to melt. **Don't let motors sit in a stalled condition!** DC motors will tolerate that better than AC motors, but it will strain your system and could cause damage.

Solar Superfridge

Once you have a PV panel installed, you can power a fridge with it. I have no idea if even high efficiency, shared refrigerators are truly sustainable on a global scale over large lengths of time. My hope in explaining high-efficiency refrigerators here is that people will ***stop using their existing grid-powered refrigerators,*** not just go out and buy another gizmo. The most energy efficient refrigerators use thermal storage, not electricity storage.

Decades ago, environmentalists recognized that refrigerators were a problem, particularly as people all over the world wanted more and more of them. In the 1990s, some scientists working at NASA consulted with a German compressor company called Secop (the compressor is the mechanism in a fridge that compresses and then expands refrigerant gas, thus making the fridge cold.) They were very happy when they successfully created a refrigerator that relied on direct drive solar energy and thermal storage alone to stay cold -- no batteries, no grid power.

One member of that team went on to found Sundanzer, a company making solar refrigerators. They developed the DDR165. We have one of those units, and it has worked great. But it’s not clear at this point if they are still making that it. Everyone seems to prefer battery powered refrigerators, if they buy a “solar” fridge.

Now we have an arrangement with Sunstar in Indiana (not to be confused with Sunstar in Canada.) They are now making direct drive refrigerators with the Secop compressors. The Sunstar units have worked well. We have sold (at cost) quite a few in Puerto Rico. Almost all "solar refrigerators" on the market are made to run with batteries. Our direct drive refrigerator runs without any batteries at all. It is about half the size of the full-sized refrigerators to which most Americans are accustomed. It is a chest design. When you are just starting out, if you don’t have a lot of food to put in the fridge, you can put in bottles of water to serve as thermal mass. It will take a thermal storage fridge a couple of days to stabilize. But once it does, it stays cold. Depending on where you set the thermostat, it may freeze at the bottom and stay cool, but not frozen, at the top. We put longer term, heavier items in the bottom, and more tender vegetables on the top trays. Overall, it works great. *It is the only fridge that has zero operational costs once installed.* That is no small matter.

The motor on the Sunstar direct drive fridge runs from 10 - 45 volts DC. You need a 120 watt PV panel or larger. Given the voltage tolerance of the unit, almost any single PV panel 120 watt or larger will do. (Look at your panel, make sure the voltage at maximum power, abbreviated Vmp, does not exceed 45). A larger panel will help the fridge run better in cloudy weather.

We have seen a lot of people try to ‘cheap out’ and avoid the $1,000+ pricetag of a solar fridge by adding batteries, inverters, and thermal mass. If you just take an ordinary, large household fridge and try to power it with batteries and an inverter, it’s going to cost a lot more than a thousand dollars. The bottom line is that we are looking for scalable solutions, and powering poorly built AC fridges with fancy electronics and batteries is not scalable.

Pumps

Some DC appliances are easy to acquire, some can be converted from AC, and some you have to configure yourself. The whole subject of pumping water is complex. There are many kinds of pumps suitable for all manner of applications. Overall, DC water pumps are the easiest DC tools to acquire. Many kinds are available. We are going to provide an overview here.

Because of the number of farmers who need to power remote water pumps, there is a large market for direct drive solar pumps. There are dozens of companies making thousands of products. As for **submersible water pumps** (well pumps), the big suppliers are Sun Pumps in the U.S., and Grundfos and Lorentz in Germany. Chinese made pumps can be tremendously variable in quality. We have dealt with two Chinese companies that make decent quality pumps, those companies being Feili and Ningbo Cheer.

The most common pump technology in use today is centrifugal. If you were to cut a snail shell in half to expose the spiral design, the impeller in a centrifugal pump looks a lot like that. The liquid enters the center, and as the spiral spins, the liquid is propelled by centrifugal force away from the center of the spiral. There are many kinds of impellers, but they all work on the same principle of flinging the liquid outward from the center of the impeller. A single impeller cannot make much pressure on the output side. Multi-impeller pumps pass water from one impeller to the next to build up pressure. Almost all well pumps in the U.S. are multi-stage centrifugal design with anywhere from a half dozen to two dozen impellers stacked on top of each other.

Centrifugal pumps work well at full design speed. At lower speeds, the centrifugal action does not work so well. This is a problem for the variable power inputs that occur with D3M. The pump companies have solved this problem a few different ways. There is a particular kind of pump that has been used industry for years that goes by the names progressive cavity, screw pump, or helical rotor. The big pump companies are all making helical rotor pumps. These pump are all ‘positive displacement,’ meaning they open and forcefully close a cavity in the pump. That means that they will pump full pressure -- though much lower volume -- at low speed. We have installed numerous solar pumps, including single stage (low pressure) and multi stage centrifugal (higher pressure), helical rotor, submersible and surface pumps.

Centrifugal pumps are the only pumps that stands up well to pumping water with sand or grit in it. You should also note that well water can often have fine grit that is largely invisible. A simple test it to get a large glass container and fill it with water. Let is set for a week or so, then look and see what has settled to the bottom. That is not a conclusive test, as very fine grit may remain invisible. The same water companies that test for bacteria in drinking water can often test for grit. The bottom line is that if you have significant grit, you have to use a centrifugal pump. (Grit can also be filtered out, but that doesn’t help your submersible pump at the bottom of a well.)

There are hundreds of different kinds of solar pumps at any price and performance range you might choose. There are numerous DC pumps designed specifically for the variable nature of direct drive. Pump technologies that will put out good pressure even at low power include piston pumps, diaphragm pumps, rotary vane pumps, flexible impeller pumps, gear pumps, and other technologies besides. While there are many technologies on the market, most solar pumps use centrifugal technology, and most of the remainder are helical rotor. Danfoss is a company that specializes in positive displacement surface pumps.

A lot of people think they can elevate a water tank and get lots of water pressure. Well, those water towers you see in small towns are quite tall. One psi (pound per square inch) is emitted from a water tank 28 inches off the ground. A vigorous shower might be 30 psi. That would require a water tank 70 feet in the air. And at eight pounds per gallon, building a tall tower to support water tanks becomes a far more expensive option that using a larger bladder tank (well tank). We use several 120 gallon well tanks at LEF. That entails some expense, but they last forever, whereas batteries do not. If one recalls earlier comments about the low mineral content and acidity of well water on the East Coast of the U.S., under those conditions at least fiber wound tanks are recommended, not steel.

What Kind of Pump Should I Use?

A general set of recommendations for pumps would be as follows:

1) For circumstances where you are pumping **well water for farm irrigation and/ or high volume domestic use**, use a multi-stage centrifugal pump. Do not buy cheap, no-name DC submersibles. Many of those die an early death. You want pumps from Sun Pumps, Grundfos, or Lorentz if you can afford it. If you need something cheap, stick with Feili or Ningbo Cheer from China. Beware Feili also makes very cheap, less durable brush motor pumps.

2) For circumstances where you want to pump **well water for domestic use** and not for irrigation, use helical rotor if the water is clean. If there is grit in the water, use a multi-stage centrifugal. The helical rotor pumps will provide consistent pressure almost regardless of the weather. The Chinese companies also make 'screw pumps' that are very similar to but much cheaper than the helical rotor pumps made by the American and European companies. Even the Chinese manufacturers are clear that the screw pumps are not as durable as the centrifugal pumps, and are certainly not recommended for any water that has grit in it. That said, it would be useful to gauge the cost and performance of Chinese vs American and European screw pumps/ helical rotors. Unfortunately, we have not had the time or resources to test these pumps adequately to determine their quality.

3) For **low pressure surface irrigation**, such as pumping creek water, use centrifugal pumps. Note that the term 'submersible' can apply to either higher pressure, very narrow pumps intended to go down a well, or fat little sump pumps that you could put into a sump, creek, pond or water tank. If you put a pump into a creek, make sure your pump isn't sucking up a lot of sand and mud. Put it on some kind of pedestal or containment in the creek. There are a lot of very cheap, and not so cheap, low pressure single stage centrifugal solar pumps.

You can also use **surface pumps** (not submersible) for this purpose. For a centrifugal pump to work, there has to be water in the pump, not air. The advantage of submersible pumps is that they are, by virtue of the pump itself being under water, always full of water. There is never a need to "prime" the pump by putting water into it. With a surface pump lifting water from a creek, one uses a foot valve below water level and pours water into the pump itself to get it started. Note that these pumps are always weaker on the input side than the output side. The spring on a true foot valve (which is a kind of check valve) is weak. A strong spring on a check valve on the intake side of a centrifugal pump can significantly reduce its performance.

We have set up a numerous small pumps for different applications. We have run belt driven piston pumps with low voltage scooter motors for irrigating crops. We run a belt driven pedestal pump for effluent for the biogas digester. We have run some small low-voltage sump pumps. With a lot of surface pumps these days, the impeller hangs on the shaft of a J frame motor and the pump is bolted to the face of the motor. That is unfortunate in that most of the industrial DC motors have a C frame. The motor shaft on the C frame motors is too short to be bolted directly to pumps made for a J frame motor. The solution is to use pedestal pumps, which can be found in many different configurations and sizes. The pedestal pumps have their own independent bearings, and are belt driven. We have used them in numerous applications.

Beware that neither a single stage AC shallow well pump nor an AC jet pump will work well on solar. A lot of people try that, and it just does not work well at all. Those single stage AC pumps are inefficient energy hogs that only work at full power. If you tie one to a battery and an inverter, it will at best take about ten times as much energy to pump your water as running a DC pump. Often the batteries weaken, and the pump doesn't work at all. A DC pump tied to the same PV supply would pump lots more water.

4) For **high pressure surface water** applications, you need a multi-stage centrifugal booster pump. Those are harder to find in a DC configuration. Sun Pumps makes a lot of booster pumps, but they are expensive. Ningbo Cheer makes a much cheaper pump of good quality that we distribute through livingenergylights.com You should note that these booster pumps put out excellent pressure, but they cannot run dry for extended periods. A single stage pump pump does not stick out far from the motor, and does not have independent bearings. The impeller is supported by the motor bearings. The multi-stage boosters are much longer, and have a water lubricated bearing at the far end of the pump. That bearing will burn out if the pump is run dry.

Washing Machines

If water pumps are the easiest machine to find in a DC configuration, washing machines may be the hardest. There are some small, low-voltage DC washing machines offered by Chinese companies. We do not have any information about them. The concern would be durability. I would be concerned that they would be destroyed by community use. An Amish company called Fisher Manufacturing in Navon PA makes washing machines meant to be powered by pressurized or a DC battery set. (No website.) Those based on Speed Queen machines. An organization called Infrastructure Angels offers a low-voltage, battery powered DC washing machine. We have no comment about these machines, other than they do not suite our needs.

What is needed is a high voltage DC, durable washing washing machine that will run direct drive. We have a working prototype at LEF. Hopefully we can make that kind of machine available in the coming months and years. The one we have will last forever, and uses a very modest amount of power. The current model does not have a spin cycle, and thus would not be suited to people using tumble dryers.

Direct Drive Shop, Kitchen, and Farm Tools

Following is a list of devices and appliances we have set up to run direct drive DC;

1) **Grain grinder** -- The one we use is called a Grainmaker. It is very well built and not cheap. There are numerous other grain grinders around, including much cheaper ones made in China. We do not have enough experience with the China mills to comment on their quality. These are belt drive, sometimes with a two-step reduction for very low rpm operation.

2) **Blender** -- We use an ordinary blender with snubbers on the switches.

3) **Insulated Solar Electric Cookers --** ISECs, we cook about 70% of our food at LEF with these cookers. They work much better than the “sun oven” style cookers. These are set up with ordinary electric cooktop burners, the set to the size of solar power input. On these we use drum switches (because the are more compact) with snubbers. We have a separate chapter to talk about cooking.

4) **Commercial Food Processing Equipment --** We set up a commercial food processing facility in Jamaica with a heavy shredder and grinder. Although Hobart is the most well known brand name in commercial food processing equipment, they use a proprietary motor that does not have a standard frame. We use Univex, and at least some of their equipment uses standard NEMA frame motors. That makes it easy to swap in DC motors. Some of the Univex equipment will accept Hobart attachments. Used Univex equipment can be purchased at much lower prices than new. On that same installation, we put in a large, heavy grain grinder from Penagos in Columbia. This equipment is all belt drive with disconnect switches.

5) **Winnowing Fans --** We have a couple of large winnowing fans we use for seed processing. These are homemade fans, like a larger version of a household box fan, with the blade mounted right onto the shaft of the motor. We have found one company called Snap Fans (https://fogco.com/snap-fan/) Our

homemade fans work great, though it takes time to find the right fan guards (grates) and what not. The Snap Fans also work well, though they are a bit costly.

6) **Silage Chopper --** Small silage choppers were made in the U.S. a hundred years ago, but the vintage ones are very hard to find. We brought in a small silage chopper from China to process organic material for the biogas digester. That is belt drive with a disconnect switch. It works well.

7) **Heating Blowers --** A fan has a blade shaped like an airplane propeller. A blower has a blade shaped like a hamster wheel, and it is used for moving air through duct systems where there is some resistance to flow. The heating blowers to each of our buildings are belt driven, direct drive. Note that we have learned to overspin our blowers. Because our power system fluctuates, and because DC motors are full torque, full rotation at any power level, you get more work out of a blower if you set up the pulleys to overspin the blower. That means that when the motor slows down a little, it is still spinning near optimum speed for the blower. This is done by simply using a slightly larger pulley on the DC motor than that which would have been used on an AC motor.

8) **Hot Water Circulator Pumps --** The pumps that pump heated solar fluid from the collectors to the storage tanks are direct drive. Each pump circuit is independent.

9) **Firewood Saw --** We don't burn a lot of firewood, but we cut the wood we need on an old fashioned buzz/ cut off saw. It is belt driven.

10) **Electric Lawnmower --** We have an electric lawnmower with a cord that runs direct drive. It has a grass catcher, and we use the grass clippings to feed Seymour, the biogas digester. This was actually set up with a PMDC motor and a bridge rectifier so the motor could be powered from AC. The rectifier got damaged, so we simply removed it. We put a drum switch on the handle bar so the operator can easily turn it on and off.

11) **Metal Lathe --** We have a fully tooled machine shop, including a very nice South Bend 14 lathe. With the mill and the lathe, we swap out the motor and use the existing drum switches.

12) **Milling Machine --** Our machine shop also includes a mill. A lathe makes round things out of metal, a mill makes all other shapes. It is belt driven, though swapping the motor was a little tricky as the old motor had an extra long shaft. We had to add a shaft extension to the DC motor, which has to be done accurately. It also has a 'direct read out,' (DRO) which measures the exact position of the cutter head. We put a DC motor on it, and that runs at 180 volts. The DRO runs at 5 volts, so that is powered by a buck circuit from the lower power cable in our shop that ties back to nickel iron batteries.

13) **Grinders --** Our machine shop has several grinders. These include a large, heavy grinder, a small grinder with a carbide sharpening stone, and a wet grinder. All of these are belt driven and controlled by disconnect switches.

14) **Compressor --** Our shop also has a medium sized compressor. It is belt driven and controlled by a disconnect switch. We run air tools some.

15) **Band Saw --** Our shop also has a metal cutting band saw. It is belt driven and controlled by a disconnect switch.

16) **Drill Press --** We have a classy old camel back drill press that dates to the late 1800s. It is belt driven and controlled by a disconnect switch.

17) **Seeds Drying Blower --** We earn our living growing open pollinated seed. We have a drying box in which we dry the seeds. A blower pulls air through the box. The same point we made earlier as regards overspinning applies here. We put a larger than spec pulley on the blower. It is belt driven, and controlled by a toggle switch with snubbers.

18) **Angle Grinder, Power Saws, Other Hanheld Tools --** There are several ways we run handheld tools. With the full voltage angle grinder (corded), we put snubbers on the switches in the handle of the grinder. The same works for a full voltage power saw, or other tools as needed. Variable speed drills may not work this way. With cordless battery tools, we take two different approaches. I do not want to

pay for those silly overpriced drill batteries, so we don't do that much. But we do use them a bit for remote installations. Some companies make battery chargers made to plug into a cigarette lighter. We either use those or buy a boost circuit to modify the manufactured battery chargers. Thus we can use our own 12 volt nickle iron battery circuit to charge drill batteries. We also take old, dead batteries and remove the battery cells. Then we attach a cord to the battery box that then connects to the dill (or other tool), and thus our cordless tools are 're-corded' and powered by a cord from the nickel iron battery set.

Resources

The capacitors we use for snubbers are Panasonic wfd2j 105jc7
https://www.mouser.com/ProductDetail/Panasonic/ECW-FD2J105J?qs=7EBvPakHacUdqsKU2gMx6w%3D%3D
Good quality DC motors like Baldor and Leeson can be expensive new. They are often available used. We have also used motors from Worldwide Electric. They are durable enough, though power delivery is not as high.
Good quality well pumps are made by Lorenz and Grundfos, both German companies. Sun Pumps in the USA also makes very good quality pumps, and in lots of sizes and voltage configurations. We have found two Chinese companies that make decent pumps at reasonable prices. Feili is a large Chinese company. Beware that some of their very cheap pumps are not brushless. We have also been purchasing pumps from Ningbo Cheer, also Chinese. Their quality seems to be the long term durability of their "screw pumps" is not certain. The screw pumps appear to be the same technology as helical rotor, but we are not 100% certain about that.
Any pump that does not specify brushless will have brushes. For a submersible well pump, you want brushless.
For circulator pumps (for hot water), we used to use a pump called El Sid. That's no longer available, so we are using pumps from U.S. Solar
https://www.ussolarpumps.com/catalog/circulating-pumps/d5-solar-hot-water-pump/
We have used DC scooter motors for various applications (from ebay). The quality is variable, and some brushless motors tolerate a wider voltage variation than others.
Surge arrestors are here
https://www.midnitesolar.com/products.php?productCat_ID=23
and here
https://www.deltala.com/products.php
https://rspsupply.com/p-8608-delta-la302dc-dc-lightning-arrestor.aspx

Chapter 7 -- If I Can't Surf the Net All Night, I Don't Want to be Part of Your Revolution

Battery research is a huge, complex field. I do not claim to be scientifically well informed about the technical aspects of all the various battery options. I do claim to know that living off-grid with a DC Microgrid and nickel iron batteries is a good life. Setting up anything electrical requires some knowledge and experience if you are going to do it safely. And so we have to issue a disclaimer here.

We are providing information for educational purposes. In reading this material, the reader agrees to take responsibility for their own work and to seek the assistance of trained personnel as appropriate. Any electrical device can generate heat or sparks, and can thus be a fire hazard. Battery systems can often generate very high amperage output, which can create a risk of fire. Any high voltage system, especially above 48 volts, can create a risk of electrical shock. Nickel iron (NiFe) batteries use potassium hydroxide (KOH) in water as an electrolyte. Generally speaking, NiFes are less toxic that other batteries, but the KOH is caustic. If you get it on your skin, it can burn your skin like concentrated bleach. If you get KOH in your eyes, it could do permanent damage. Always wear eye protection when working with KOH. Follow manufacturers recommendations in handling batteries and chemicals.

How Many Batteries Do I Need?

All of the standard solar design manuals are going to assume you are setting up a battery system to be used as a bulk energy supply. You do not want to do that. It's expensive and ineffective. Almost anything that has a motor -- appliances, shop tools, heating systems, water pumps -- are NOT going to run off or your batteries. There are some minor exceptions. Small motors that run for a very short period of time are fine. For instance, with our old ‘re-corded’ cordless tools, they run from our nickel-iron (NiFe) battery set. But these are small motors that run for a short period of time. Any major appliance that runs for any length of time should NOT be powered from your battery set.

The primary battery set at LEF is 100 amp hour (see below for more about electrical units). That set has performed miraculously well. It has powered all of the lighting needs, as well as powering some other functions, for 10 people for 15 years. In the last year or so, we have found ourselves with more people using more old laptops. Those are energy hogs in our system. We added a second NiFe battery set to support electronics. That prevents the computer users from making the lights go out. We do some rationing of computer use in the cloudiest days of winter.

Americans are always focused on their own household, or farmstead if they are rural. As many times as I repeat the importance of shared use, I either get ignored, or people simply take the tools I propose that they use and try to apply them to their own household or farm. I can tell you this about setting up household off-grid systems; No system is going to work if you leave lights and appliances running all the time as is the habit for most people. Trying to build a system big enough to meet large energy demands is always going to be much, much more expensive than moderating those demands. Share, insulate, use thermal storage -- that is by far the cheapest way to power your energy needs.

Productivism

Ozzie Zehner coined the term "productivism" to identify the focus on energy production rather than energy use. The term is focused primarily on large, industrial energy systems used to power the grid. But the focus on productivism is decades old in the U.S., and the impacts can have a big impact on you personally. The norm for solar energy systems for decades has been to add solar electrical systems to badly insulated buildings with heavy energy consuming devices. Within a few miles of where I sit are numerous buildings with defunct solar equipment. The results do not work well.

Most of all, do not get suckered into buying big lead-acid battery sets because they are so cheap. Do not buy bulk expensive off-grid systems that are intended to run all of your AC appliances. That is the only thing on the market as far as ordinary suppliers go. It will cost you a fortune over time, and leave you in the dark to boot.

At this point, we distribute (through Living Energy Lights) 55 and 100 amp hour NiFe battery sets. The 55 amp hour sets are more enough for lighting even for a large household. In any circumstance where people are using electronics and computers, a second battery set to cover those works well. The bottom line is that **i**nvesting money in insulation and better energy systems is going to produce much better results than a larger battery set. If you are in a boat and the boat is leaking, fix the leak. Buying ever larger pumps is a loosing game.

System Configuration

Most battery systems are going to be low voltage. Standardizing to 12 volts nominal is wise, because that is an automotive voltage. There is a lot of equipment available in 12 volts, from phone chargers, USB converters, fans, and lights. At Living Energy Farm, we have a high voltage system with no batteries. Almost everything else runs as 12 volts DC.

Thomas Edison created nickel iron (NiFe) batteries in the commercial sense. With modern hybrid cars, a large electrical system is often powered by a lot of small batteries. The idea is that if one small battery goes bad, then you can replace just that cell without having to replace a large battery. Thomas Edison had the same idea. He created NiFes in 1.2 volt cells. Those were then stacked in series to make 12 volt sets, or higher voltage sets as well.

Batteries always have a high ampacity regardless of voltage. That means they can put out a large volume of electricity quickly, which means they can melt wires and start fires if not properly installed. Always use fuses or DC circuit breakers when connecting wires to batteries. The DC breakers are more accurate, and more expensive.

Make sure you have proper wire sizing. That is a complex subject. Trying to simplify it here would do more harm than good. You need to have access to someone who understands wire sizing. For household wiring, the judgment of an experienced electrician is more than adequate. For industrial systems, some very complex math is involved. There are online wire size calculators (voltage drop calculators), but understanding the output from such calculators is predicated on some experience with the materials involved.

Putting batteries in series would involve going from the positive to the negative terminal of each battery. This is series wiring. Most battery suppliers provide connector bars for this purpose. Again, make sure any wire you use appropriately sized and fuses and/ or circuit breakers are used.

Make sure there is an enclosure around the batteries that can handle sparks or fire. Under normal building code, all of the electrical connections in any house are inside fire resistant enclosures. If there is ever a weakness in any electrical connection that generates heat, then that should be inside an enclosure. We use metal boxes that we fabricate. NiFes generate a small amount of hydrogen gas while charging. Small NiFe sets generate a relatively small amount of hydrogen. For small battery sets, including the "larger" 100 amp hour sets like we use at LEF, your enclosure should have some modest natural ventilation. Consult battery manufacturer recommendations, particularly if you are installing larger NiFe sets.

It is strongly recommended that you attach a ground wire to the frame of your PV panels or windmill. The wire is then connected to one more more ground rods. It is also recommended that you put in a surge arrestor. Follow the instructions that come with the surge arrestor. They range from $50 to $100 generally. Very small solar electrical systems often are not grounded and often do not have a surge arrestor, but it is desirable to have both. You might consider unplugging expensive electronic equipment in bad weather, especially if it is plugged into a small system.

Charge Controllers

The most efficient, and most expensive, charge controllers on the market these days are called MPPT. That stands for maximum power point tracking. The older, cheaper technology is called PWM, or pulse width modulation. We have used a number of both kids. We find the PWM controllers to be more than adequate, but not the cheap junk. (Xantrex C-series, C-35, C-40, C-60 work fine and have NiFe settings.) The ten dollar charge controllers almost all have fixed charge voltages which will not work with NiFe batteries. The PWM controllers do not adjust voltage particularly. If you want to use a modern 30+ volt panel to charge a 12 volt battery set, you would need a MPPT controller to do that efficiently. The costs of MPPT controllers has come down, and we are using them more than we used to.

Amp Hours

Amp-Hour (Ah) is the unit used to rate batteries. This tells how much amperage flow over time a given battery (or set) can support, independent of voltage. Once you add voltage into the calculation, then you will know the number of watts, or how much actual work can be done. If a 12 volt lead-acid battery is rated for about 300 AH, at 12 V that's 3600 Watts for one hour or 360 watts for 10 hours, etc. The problem is that lead-acid batteries only actually deliver their rated AH electrical output the day they are made, not anytime thereafter. Nickel iron (NiFe) batteries outperform other batteries in off-grid applications.

Electrical Polarity

Many, not all, electrical circuits have a polarity, denoted by + (positive) and - (negative) signs. With household current, the black wire is the hot wire -- the one that can hurt you. (With high voltage/ 220 volt, industrial AC, or European and Asian systems, all wires but the ground are hot.)

With DC systems, black is - and red is +. With most DC motors, you can reverse direction of the motor by swapping + and - wires. When you look at your voltmeter, the black lead should be attached to the plug labeled "com," for common. The red wire should be connected to a plug with numerous symbols, including V. When you test a live circuit with a digital meter, if you put the red wire on the + side, you will get a positive number. If the number on the screen has a negative sign (like - 240), then you have the red wire on the negative side. Reverse and test again. Labeling the + side with red electrical tape is often a good idea.

Battery Electrolyte

The electrolyte in NiFes is potassium hydroxide (KOH) and distilled water. The distilled water is cheap to buy or easy to make, but it must be distilled, NOT filtered, bottled, tap water, or anything other than distilled. The distillation process removes the mineral content of the water. Using any other kind of water would cause a build up of minerals in the battery and cause them to degrade.

KOH is also called potash and is used for making soap, fertilizer, and biodiesel. It is caustic. If you get it on your skin, it makes your skin slippery, like concentrated bleach. If you got it in your eyes, it could blind you. Any time you are working with KOH, make sure you do not breath the dust, make sure you wear eye protection and gloves, and make sure you have eye-wash capacity on hand.

The electrolyte in NiFe batteries will need changing every 5 - 8 years if it has no lithium hydroxide in it. It will need to changing every 8 - 10 years if there is lithium hydroxide in it. The lithium is harder to find than the KOH.

Very old Edison batteries can generally be reconditioned by washing them out and adding new electrolyte, even when they are many decades old. That's fun!

If you mix electrolyte, then you must make sure you add KOH SLOWLY into water. The KOH fizzes and generates heat as it is dissolved into the water. Do NOT pour water into KOH. That would cause a rapid reaction that would be unpleasant and dangerous.

The baseline ratio by weight, assuming your water is cool, is 3 parts (grams) KOH 10 parts (grams) water. Make sure everything is clean, including your mixing pail, measuring cups, etc. You can use a plastic or stainless steel mixing spoon, but not a wooden one. The final result can be tested with a hydrometer. The target density is 1.2 g/ cm3 (1.2 grams per cubic centimeter). Tolerance is between 1.19 and 1.21.

Let the mixture cool before you put it in the batteries. Some manufacturers recommend that you pump the electrolyte rather than pouring it so you don't spill. You can pour, but do so carefully. Wipe up spill. Remember, the electrolyte can burn you, so use gloves and be careful. The batteries are marked as to the electrolyte fill level. Clean up when you are done. As the batteries are used, they boil off water. At that point, you add ONLY distilled water, not more electrolyte. We water our batteries every month or so in summer. They need less water in winter.

Chapter 8 -- Cooking With Solar Energy

For the first 14 years of life at LEF, we used wood-fired rocket stoves to cook a lot of our food. Now, finally, we are cooking all of our food with solar cookers and biogas. In terms of quality of life, this has been a big improvement for us. This chapter is about solar cookers. The next chapter covers biogas.

Food is essential for life, but storing and preparing food comes at a price. American kitchens use more energy than American farms, and American refrigerators use more energy than the tractors on American farms. Cooking entirely with renewable energy has been a challenge at LEF. To take a hot shower in winter one needs water heated to a 110 F or so. To cook, one needs to generate several hundred degrees of heat. That is much more challenging with cost-effective renewable energy systems.

We first learned about Insulated Solar Electric Cookers, or ISECs, from Pete Schwartz, a professor at Cal Poly. We have designed ISECs that are anywhere from 100 to 1400 watts of power. Pete's designs focused on small, inexpensive cookers that cook slowly. We have tried that approach at LEF. On a partly cloudy day, the low powered cookers simply don't cook, and the cooks don't use them. We use cookers that are tied into our D3M. We use several cookers ranging in power from 300 to 1400 watts. Our largest cooker, which is tied to our 1400 watt, 180 volt array, will cook when the sky is partly cloudy, and regardless of how brutally cold it is outside. That is by far our most useful cooker.

Our cookers are very simple. We started out making homemade burners, but have largely abandoned that approach. For our use and for the cookers we build and distribute through Living Energy Lights, we purchase manufactured burners. These are stovetop electric coils that you see on old fashioned electric stoves.

The more powerful ISECs cook faster and more reliably, and that is more convenient. The smaller cookers can be made very inexpensively, and are still quite effective. All ISECs are much more efficient than traditional cooking methods, though some cook quite slowly.

Other solar cookers, such as small solar ovens, are more well-known that ISECs. The big limitation of solar ovens is that they only work in bright, sunny, moderately warm weather. The cook also has to run back and forth between the solar cooker and the kitchen. ISECs do not solve these problems completely, but they do in large measure. With an ISEC, you can cook in partly cloudy weather, indoors in your own kitchen, when it is bitterly cold outside. No other solar cooker comes close to that. A lot of organizations promote technologies for low income countries that no one would use in an industrialized country. At LEF, we use what we encourage others to use. That is no small issue. Before we had ISECs, we did maybe 5% of our total annual cooking on solar cookers. With ISECs, that number is now about 70%. That's a big difference, and speaks to the efficacy of this technology.

Cheap Little ISECs

Our first goal in building ISEC cookers was to build the cheapest effective unit we could build. Without reviewing our various experiments that taught us what would *not* work, the cheapest, simplest cookers we have built are the Perl bucket cookers. We used a five gallon bucket filled with perlite. The perlite works reasonably well as insulation, and does not degrade at cooking temperatures. We make burners out of nickel chromium (nichrome) wire. You know when you push the lever on a regular toaster and you see those wires that glow red? That is nichrome. It is a kind of metal that has a high internal resistance and thus converts electricity to heat. Most electric heaters use nichrome elements. We make a lid for the Perl with rockwool insulation and a flame-proof material (aramid or high temperature fiberglass). A steam table drop-in pot (Bain Marie) drops into the cooker, which cooks like a crock pot. The Cal Poly project started with 100 watt, well-insulated cookers. That's where we started. A 100 watt Perl Cooker will cook one meal a day. It's fine to innovate if you want. But beware, anything that can cook your food can set itself on fire and burn down your house. Cooking is by far the leading cause of home fires.

More Powerful ISECs

We wanted stronger and more versatile cookers. We have sheet metal fabrication tools that we set up for building battery kits. Those tools consists of a big scissor called a shear, and a bending tool called a brake. With those tools, it's quite easy and inexpensive to make sheet metal boxes. Most of our cookers are Roxy cookers, so-called because they are built with rockwool insulation around a sheet metal box. All of our cookers are built entirely with non-flammable materials. The Roxy cookers can be built with homemade burners or range burners made to be used on electric stovetops. Though we experimented with a number of different kinds of cookers, we have standardized to a Roxy cooker set up like a regular oven with a door that opens. They are made of metal and insulated. Pots or trays may be put inside. Pots can be put on the burner and so the Roxy functions like a range.

A48 volt, 330 watt cooker can cook two meals a day in sunny weather. Our largest cooker has a couple of settings 500 or 1200 watts. It can cook two meals a day even in partly cloudy weather. Make note, a "normal" residential oven has 7,000 - 10,000 watts of power or more. The insulation in an ISEC makes a big difference.

If you want to build an ISEC, you have to decide how to configure your electrical system properly to get maximum use out of you PV panels and cook food in the process. When you use a conventional electric or gas stove, you are concerned about cooking your food, not using all of the gas or electricity available. If you want to set up an ISEC with PV panels in a small electrical system, you want to do exactly that -- use all of the watts available. That means your burner must be sized properly. If your burner is just the right size, you can capture nearly 100% of the energy output of your solar panel(s). If your burner (resistor) is too large or too small, a lot of the energy being produced by your PV panel will not be used.

With our D3M at LEF, our high voltage circuit is 180 volts, 8 amps, about 1400 watts. On any given day, we are running 3 - 6 motors and cooking as well. We really don't care if the high voltage ISEC uses all of the electricity available because we are simultaneously using that energy for many other purposes. We juggle loads depending on need. That involves some management, but we are able to squeeze the blood out of our watts in a pretty extraordinary fashion. Just the other day, I made note of our daily usage. In a single moderately sunny, cold day in the fall we cooked most of our food with ISECs, machined some heavy steel parts in the shop, heated our main house, ran the food dryer all day, ran the seed dryer all day, and cut firewood with a big electric buzz saw. That kind of energy system integration makes for an extreme efficiency relative to other energy systems. Such is the value of integrating the ISECs into a DC Microgrid in a community setting.

ISECs VS Sun Ovens, Scheffler Reflectors, and Other Cookers

A lot of solar cookers have been developed over the years. We often look at technology like we look at other consumer items -- the more options the better. But the bottom line is that some things work a lot better than others. At LEF, we have used solar ovens (Sun Ovens and similar), as well as parobolic cookers. The latter look like a satellite dish covered in tin foil. These actually work in cooler weather than the solar ovens. There are also a number of other cookers using vacuum tubes and what not. One of the more sophisticated cookers is called a Scheffler Reflector. It is like a parabolic dish, but it made up of many small reflectors and can be aimed at a particular location.

A lot of people who work with renewable energy hold hope of wider adoption. The reality is that few people choose to cook on solar. Many issues, including cost, convenience, and reliability come into play. In that regard, LEF is a very useful testing ground. We encourage and educated our members to use solar cookers, but at the end of the day, they cook as they choose. Before ISECs, even with several kinds of solar cookers available, about 5% of our total annual food was cooked with solar. With ISECs, we now cook about 70% of our food on ISECs. That's a huge difference.

The various failures of different solar cooking projects are equally instructive. An elderly friend of mine spent several decades running solar cooking programs in Latin America. He would bring in materials, and do workshops with village women. He was building solar ovens, which are among the easiest of solar cookers to build. The last time I spoke with him, his comment was that after all those years of work, not a single solar oven was still in use. It's no mystery really. Our solar ovens are not in use at all at this point. The ISECs work much better, and the cooks like them a lot more.

At LEF, we spent and unfortunate amount of time (about 7 years) trying to build a simplified high temperature solar thermal system. That is done industrially quite a bit, and is actually a lot more efficient than PV. It did not work for us to try to miniaturize that technology. It was too complex and expensive, and we have too many clouds.

Small, solar powered pressure cookers are spreading, with outside funding, in Sub-Saharan Africa. That project will go it's own direction in time. We will point out that the western focus on individualism appears to have an overriding impact on how many technologies develop. The efficiency of D3M is extreme if 10 people are using the system. Much less so if only a small family is using it. Because of the focus on individualism, with the personal experience of grid power, it seems that new energy systems are always focused on one power supply for one end use. Thus a set of PV panels is supposed to power a cooker, instead of being integrated into a D3M system. The latter is radically more cost effective.

Scheffler Reflectors have been built around the world. They are far more complex than a solar oven, and more effective. We have never built one at LEF, though we did take the time to design a process to build them (using a small laser to align all the mirrors).

At the end of the day, D3M is a system that fulfills many needs from one power source, cooking with ISECs being one of those needs. Particularly when you see ISECs embedded in the D3M system, it's a lot like AC power in that regard. When you purchase a new appliance for your house, you don't have to think about a new power supply for every radio, alarm clock, or toaster. They all plug into the same power supply. The same is largely true with D3M. An ISEC is just anther 'toaster,' but a darn useful one in this case. The breakdown to the spread of D3M is that in industrialized countries, our conception of technology is always based on the individual, not building energy systems for 10 or more people. The same prejudice is influencing which technologies we promote for use in non-industrial countries. D3M is dramatically more efficient. I am hoping we can break though these obstacles over time.

Resources:

Information about ISECs can be found at http://sharedcurriculum.peteschwartz.net/solar-electric-cooking/ and http://sharedcurriculum.peteschwartz.net/direct-dc-solar-research/

This is a photo of the Roxy ISEC cookers we make and distribute (in very limited quantity) through Living Energy Lights (.com). They are stainless on the inside with rockwool insulation. They work quite well.

Chapter 9 -- Creating a Community Scale Biogas System in a Temperate Climate

Improvements in biogas production have had a huge impact on our lives at LEF in recent times. Funny note, here's a line from *Empowering Communities*, 2nd Edition: "By the time we hit the third edition of Empowering Communities, I am sure we will have a lot more to say about biogas." Wow -- indeed we do! Biogas is a big part of our world at this point. And we figured it might be....

Making biogas is quite easy. The two big issues are simply keeping it warm and finding feedstock. The reason everyone doesn't already have a biogas digester is simply that it's quite a bit of work to take care of one. And in a temperate/ cold climate, keeping the digester warm enough is very challenging.

We built our first biogas digester 14 years ago. It was a 55 gallon plastic drum. We ran it in summer and made no effort to insulate it or provide any auxiliary heat. The amount of gas it produced would cook one meal every 10 days or so. It was not all that useful.

After about 7 years of trying to build a high temperature solar heat storage system for cooking, we installed our second biogas digester about five years ago. It was a few hundred gallons. We put a solar heating coil under it, connected to a flat plate solar collector just like you would use for creating hot water. We wrapped six inches of commercial insulation around it. We produced a lot of gas in the warmer months. In the summer, we went for weeks at a time burning no wood at all, cooking for a ten people or more using ISECs and biogas. That was sweet for us. But once winter came, we were back to using firewood for cooking.

A couple of years ago, we built our third digester. His name is Seymour, and he is a 2000 gallon plastic tank (seven feet tall, seven feet diameter). Given the gas bubble at the top of the tank, actual digester capacity is about 1600 gallons. Seymour has a solar heating coil inside of it (as opposed to under it) connected to a five flat plate solar collectors like you would use on a hot water system. (About 100 square feet of collector area). He has two layers of straw bales around him, totaling about 36 inches of straw.

We ran into various problems in setting up Seymour. We had problems with leaks where we connected pipes to the tank. Without realizing it, we built an excellent rat habitat with all that warm straw. The rats chewed some of our pipes. The solution is to control rodents (always an issue on a farm anyway), and to make sure any pipes buried in insulation are metal, or wrapped in rat ware (1/4 inch hardware cloth). Then our stainless solar heating coil leaked. We had used brass compression fittings. We went back and swapped in swagelock fittings. Those aren't cheap, but they are much better for stainless than brass fittings.

Then we overheated poor Seymour. On paper, there are three kinds of archaea (the micro-organisms that consume organic material and emit methane.) Methane is natural gas, and biogas is mostly methane. Cryophilic archaea will emit gas at low temperatures. Mesophilic archaea will emit gas at medium temperatures (85 F to 110 F seems to be the optimal range). Thermophylic archaea will emit gas even in very hot temperatures that kill almost everything else. But when we let the summertime temperature in Seymour get up to 120 F or so, it all went wrong. Talking to other folks, it seems like mesophylic archaea are very robust, and thermophylic archaea are not. Some commercial biogas operations use thermophylic archaea. It seems like they maintain a much more controlled environment. The solution is to stick with mesophillic temperatures. To achieve that, we installed a diversion valve and a heat sink -- a tank of water with some copper pipe in it -- to divert heat at the peak of summer.

The rats, leaks, overheating, and what not kept setting us back. Problems in the winter have a long recovery time. And once Seymour got chilly, he wouldn't make much gas. And biogas was one of many projects. Add all that up, and it took a couple of years for Seymour to catch his stride. But once he did, everything changed.

It seems that with any digester, the archaea colony is pretty delicate at first. Not warm enough, and the archaea don't make gas. Not enough food, and they don't make gas. Too much food, and they make lots of carbon dioxide and not biogas. At best, it takes a month or two to start making good gas. That was true with each of our digesters. The lore of biogas is that digesters improve with age. It is true, and the difference is striking. With our second digester, we produced a lot of gas after we had fed it for a couple of years (though we couldn't keep it warm in winter). Even after we cut off food and heat, it kept making gas for a long time, and we made use of it.

With Seymour, once his archaea culture was approaching a year old, he starting making a LOT of gas. I tell people that the *Chinese Biogas Manual* is an excellent in resource for understanding biogas. There are a lot of youtube heros who make things work, but how a technology fits into a community context is what really matters. In China, they took wheat straw and other cellulose, and using some manure, water, and aeration, ran a quick composting treatment to break the material down part way. Then they fed it to the digesters. I had imagined we would do something similar, running something like a modest haying operation. I bought a small Chinese, hand fed silage chopper in preparation for chopping up some of our late summer tall grass.

Our most diligent member as regards taking care of daily tasks is Otto. He takes care of Seymour. He had the idea of using a direct drive electric lawnmower (we love our direct drive!), and collecting the grass clippings for Seymour. We also have a biogas toilet with a hand pump that pushes human wastes into Seymour. I have read that human waste does not have a lot of energy in it, but it does have nitrogen. This helps the digestion process, so I understand. Much to our surprise (more like shock and amazement), the grass clippings from a modest area of our front yard, augmented with human wastes and kitchen scraps, is enough food (in summer at least) for Seymour to produce far more gas than we could use. We went through a time of burning off excess gas, and building more storage. Biogas is methane, and that is a potent greenhouse gas. If you have to get rid of it, you want to burn it, not just vent it. And you want to be mindful of staying on top of leaks.

Learning from our experience, we now keep Seymour on a diet, and at moderate temperatures. We have imported biogas storage bags. (We tried to use air mattresses as biogas storage, but that didn't work.) Now we have gotten pretty good and pushing the feed rate up and down as we need more or less gas. There is a delay time of some days while Seymour adjusts. But we have all the gas we want, and then some. Goodbye firewood! The fact that we can make so much gas with so little feedstock is mind boggling. If anyone tells you biogas digesters need manure from cattle to make gas, they are wrong. Fresh cow manure is certainly helpful in getting a biogas digester started. Cows have live archaea in their digestive tract. But the daily food for a biogas digester need not contain any manure from farm animals. Once a digester is mature, they are extremely tolerant of.... everything and anything, it seems.

Building a Large(ish) Biogas Digester

We learned some things building Seymour. We faced a challenge with trying to attach the large feed pipe to the side of the tank at the bottom. To avoid the pipe intersecting the side of the tank at a sharp angle, we used heavy plastics (like the plastic wood they use for some furniture) and some fancy epoxies and hot glues to build a box where our large pipe could enter the digester. The box is on the side of the tank at the bottom, and the pipe comes in the top of the box. I have a lot of experience as a plumber. Various other folks at LEF worked on it as well. But even after buying and using various expensive epoxies and different kinds of hot glue, we could not come to a good solution as regards the assembly of a leak-free box. (Silicone caulk was a dismal failure in this application.) In retrospect, the preferred solution is a smaller (3 inch) pipe connected to some kind of pump, then connected to the tank with pipe flanges. Then the sealant only has to work as a sealant, not an adhesive.

We have had to invent a few gizmos to make our biogas work. It is challenging to grind the material going into the digester. The flow of kitchen compost makes great digester food, but all the rinds and whatnot need to be broken up. The material going into a digester should look like oatmeal -- kind of fluid, but thick with organic matter. After looking at and trying various devices that crush up our organic waste, we built a simple hand cranked grinder. It took some welding, but it is a simple device and easy to build. See photo below. It works great. A commercial ice crusher would also work for this purpose, but it needs to be one of the larger, belt driven units, not a plastic counter-top unit.

With a big digester like Seymour, it is challenging to get organic material into the digester. The kit we used (digester number two) had a pipe going into it that was narrow and had an unfortunate elbow in it. For Seymour, we used a larger pipe, but then we found that we were fighting the static pressure in the tank (imagine trying to push a volleyball to the bottom of a pool over and over). With our homemade grinder and a bit of water, we get a slurry that can be pumped into the tank. We experimented with various methods of moving the slurry, and finally decided to invent our own pump. We invented a unique kind of piston pump in which both the piston and the sleeve around the piston move. This is useful for pumping fibrous material. As we head to press, we are moving toward building a homemade peristaltic pump. The piston pump works pretty, but we have had issues with highly fibrous material clogging the check valve on the output side. The peristaltic pump should work better. It works by squeezing a long tube over and over. (See illustrations that follow.)

Our homemade grinder and pump solution makes for a much better option for setting up biogas systems in low-income communities around the world than other options we have seen. There are many organizations around the world, as well as government programs in some countries promoting biogas. We wish them the best of luck. The simplest designs use plastic bags, which are not very durable. Plastic tanks of various sizes are relatively inexpensive, though what seems cheap to us is no doubt quite expensive for working class people in other parts of the world. At LEF, our primary outreach projects are currently in the Caribbean. There many people have a plastic tank on their roof for water because wells are too expensive. Our grinder-pump solution would allow a person to mostly use the existing taps on an ordinary water tank. Any additional taps would be modest in size, and thus easy to install using ordinary pipe flanges and silicone caulk. We hope to pursue this solution in with our outreach projects.

If you live in an area where it gets cold in winter, keeping a community-scale biogas system warm enough year-round is the biggest challenge. We are told that the temperature inside the digester should not change too quickly, but that is not an issue if using solar thermal energy to heat a digester.

Every day a biogas digester creates effluent, and that liquid is good fertilizer. That's a big reason why these renewable energy systems have to be community-scale. An individual or single family cannot afford the time to build or care for a digester. For industrial biogas, large volumes of organic matter (feedstock) cannot be hauled over long distances economically. Industrial biogas would (and does) overwhelm the need of local lands for fertilizer, and thus makes that potential resource into pollution. It's a huge relief for us to cook with biogas as opposed to rocket stoves, particularly cooking breakfast first thing in the morning.

Part of the reason we have put so much effort into our biogas is that we need a farm-grown fuel to power a small tractor and a harvesting machine on our farm. Batteries, even the fancy new lithium ones, do not last for decades the way an internal combustion engine does. The tractors we have used at LEF have dated from the 1930s to the 1970s. Nothing newer than that. When you look at the number of battery replacements to keep a tractor running over many decades, that's why we don't want batteries. They are just too expensive over time. We have looked at woodgas, turpentine, biogas, and steam to power mobile machines. We have no illusions about powering cars driving all over with biogas or any other homemade fuel. But a small tractor running on a farm is a big help. That's another chapter.

There are many organizations around the world that try to help low income communities. The difference at LEF is that we live with the same technologies that we promote. We do not advocate second-rate solutions for others. We are hopeful that the improvements we are making in our biogas systems will be useful for other people around the world.

Composting Toilets

Composting toilets are another option (other than a biogas digester) for processing human waste. Flush toilets have a terrible impact. They increase water use enormously. They make useful nutrients into pollution. Even on a modest community scale, they would require an increase in water inputs and sewage treatment outputs that set in motion an expensive set of choices with increased water supply (that cannot be easily supported by our daylight drive energy systems) and septic tanks with drainfields. Legally, we were stuck putting in a drainfield at LEF. It was a painful waste of time and money.

The easiest way to process human waste is with a composting toilet. The simplest composting toilets are moldering toilets in that the material inside the toilet is not turned or actively aerated. The advantages are that they are easy to build, they do a good job of controlling potential pathogens, and they require almost nothing in the way of daily labor. The disadvantages are that the nitrogen content of human waste is largely lost, and that they invariably attract a certain number of insects in summer. Nitrogen is very valuable for enhancing the growth of plants. The insects are of no great concern to those of us who have lived this way for many years. But for folks used to living in more sterile environments, the soldier flies buzzing around (they look like wasps but are actually beneficial) are the source of some distress.

Our moldering toilet is made up of a cinderblock tank. (One simply keeps laying blocks up from the footing to a height of 4 feet or so, then reinforces vertical cores every 4 feet or so with rebar and concrete.) The tank is divided into two. Each side is used for about a year. Once a year in spring we remove the material from the side of the moldering toilet that has not been in use. The material at that point mostly just looks like woodchips/ sawdust. State regulations require that the material be buried. We put it appropriately under the fruit trees. A moldering toilet relies on time more than heat to neutralize potential pathogens.

Another method of handling human waste is “humanure” whereby human wastes are collected and composted. That process probably has better nutrient recovery (as regards nitrogen at least), but involves more daily work. The daily handling of human waste could open more opportunities for the spread of pathogens, but that is not an issue where good sanitary practices are followed and running water (for cleanup) is available.

Yet another method of handling human waste are composting toilets whereby the material in the toilet is actually aerated. There are numerous modern per-manufactured units available, and lots of homemade designs as well. I have built them in the past, but at this point I prefer moldering toilets. The simple moldering setup is much simpler and effective, and does not clog.

At this point, we are transitioning to putting human waste in our biogas digester. The research we have seen indicates that active biogas digesters neutralize pathogens. My belief is that nitrogen recovery is better than a moldering toilet. The data supports that assertion. With our moldering toilets, they emit a strong ammonia odor every spring as they warm up and all the nitrogen (ammonium nitrate) is evaporated away. The biogas toilets emit effluent every day, and nitrogen is recovered there.

Resources for Composting Toilets;

Joseph Jenkins has written both *The Compost Toilet Handbook* and *The Humanure Handbook*, both of which are useful books.
The Chinese Biogas Manual reports some information regarding nutrient recover and pathogen control.

Resources for biogas;
The best book for giving you an overall sense of how community scale biogas works is *The Chinese Biogas Manual.* It is available for download from numerous sites on the web, including https://www.tngun.com/wp-content/uploads/A-Chinese-Biogas-Manual.pdf
Another excellent document is *Biogas Plants* by Ludwig Sasse, available here https://www.build-a-biogas-plant.com/PDF/BiogasPlants_Sasse.pdf
The most accessible pre-manufactured unit is from https://www.homebiogas.com/
The unit is simply two sturdy plastic bags, ones for the digester, one for gas storage. The kits have little or no insulation, and are thus made for warm climates. The accessories are helpful. The biogas burner is excellent, and the low-flush toilet is also very good. Overall, using a large plastic tank and the accessories from Home Biogas is what we would recommend.
See also *The Biogas Handbook* by David House
We have also found a great organization called The Northeast Biogas Initiative. See northeastbiogas.com

LEF's Biogas Biomass Grinder

The core of our biomass grinder is a 1.25 inch "schedule 80" pipe with heavy blades welded onto it. Ordinary 1.5 inch pipe couplings can be used as cheap bearings, or 1-11/16 pillow block bearings can be used.

The grinder blades chop and push material through heavy steel slots in the base.

This is the completed grinder after it has been in use for a while. The long handle makes it possible to grind even tough squash rinds and what not. It works quite well.

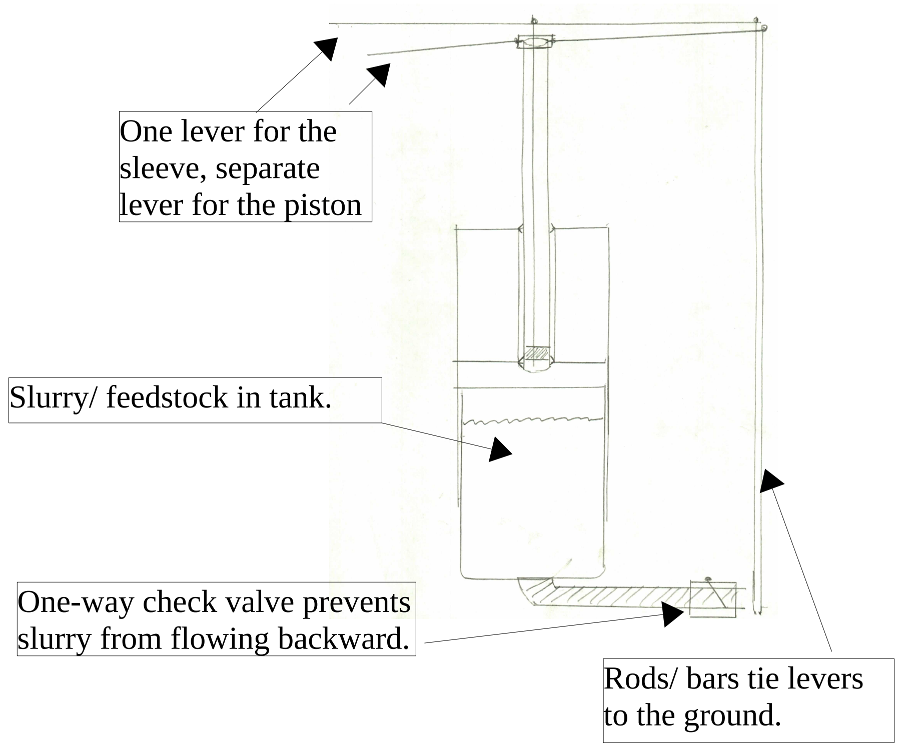
LEF’s Biogas Slurry Pump

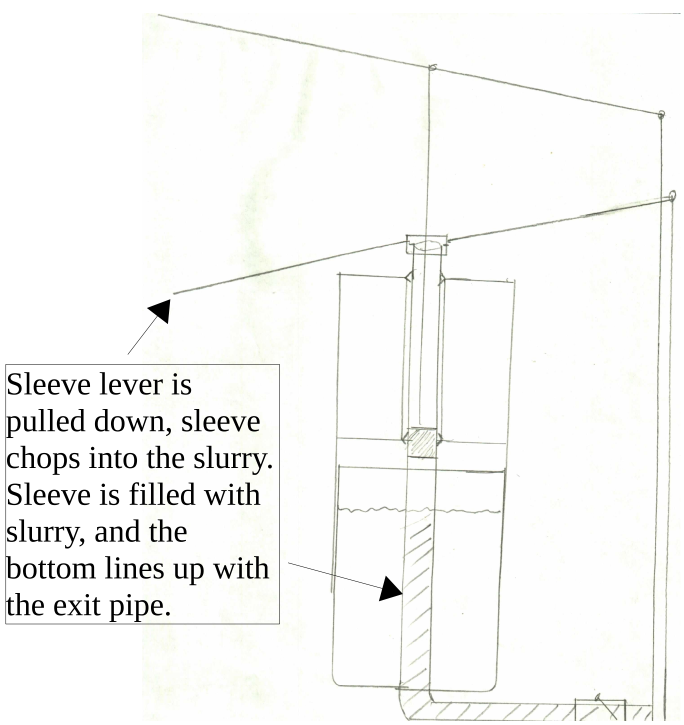
Piston and sleeve assembly for our homemade sludge pump. The outer sleeve is stainless in this picture, but it could be plastic. Inside the sleeve is a plastic piston. The sleeve and piston are attached to levers and move independently.

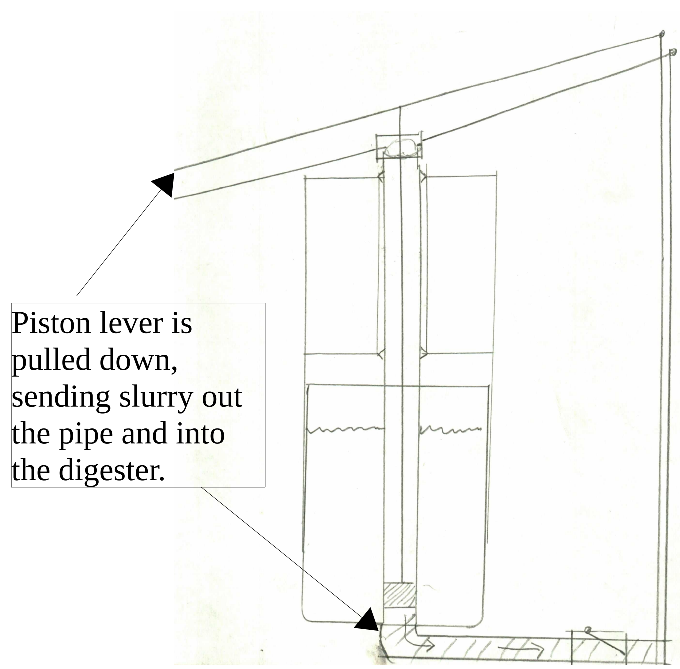
This is the assembled slurry pump. The sleeve and piston are pulled up together. Then the sleeve is dropped down, which cuts into the thick slurry which fills the inside of the sleeve. The piston is then pushed down, which pushes the slurry into the tank. Then you lift both sleeve and piston and repeat. This pump works quite well.

There is a check valve here, with an external lever. It is critical to the function of the pump. Given the coarse and fibrous material being pumped, it clogs at times. It is easily unclogged by manually lifting the check valve flapper lever while pushing down the pump piston at the same time.

Operation Sequence of LEF's Biogas Slurry Pump



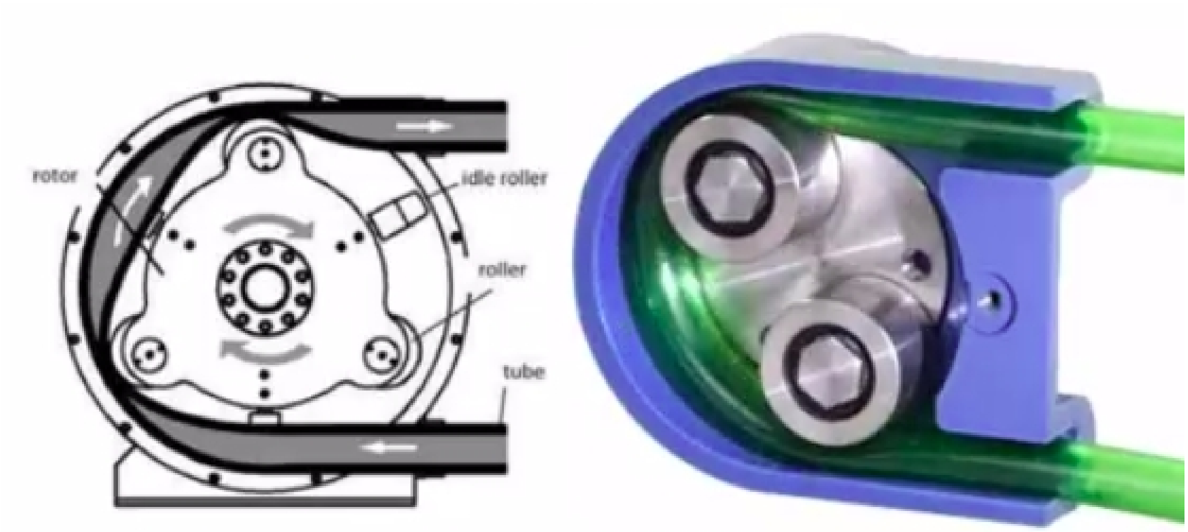




The piston pump we invented has worked pretty well. The tricky part is the check valve on the output. That can get clogged, especially if more fibrous material is used, such as grass clippings. Large check valves are also expensive.

In looking at alternatives, we going to make a peristaltic pump. Two images of peristaltic pumps are below. Peristaltic pumps have a flexible tube, and a rotating mechanism with rollers that push material through the tube. Imagine a mechanical snake that can swallow one mouse after another all day long. Small peristaltic pumps are used a lot in industry as metering pumps to push a measured amount of chemicals down a tube.

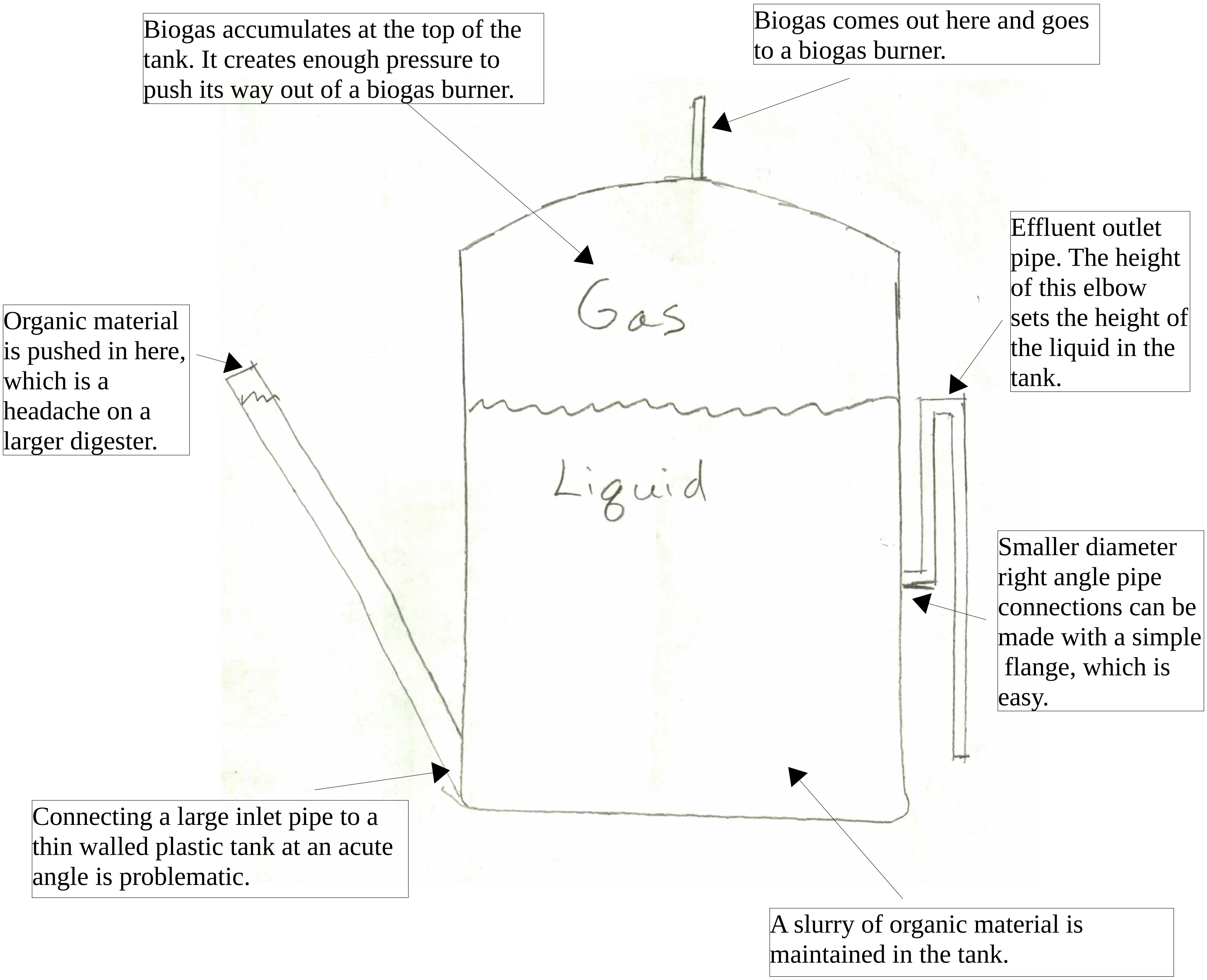
Our pump will have the advantage of not needing a check valve, and thus it should handle fibrous material easily. We can also motorize such a pump very easily using a direct drive DC pump.



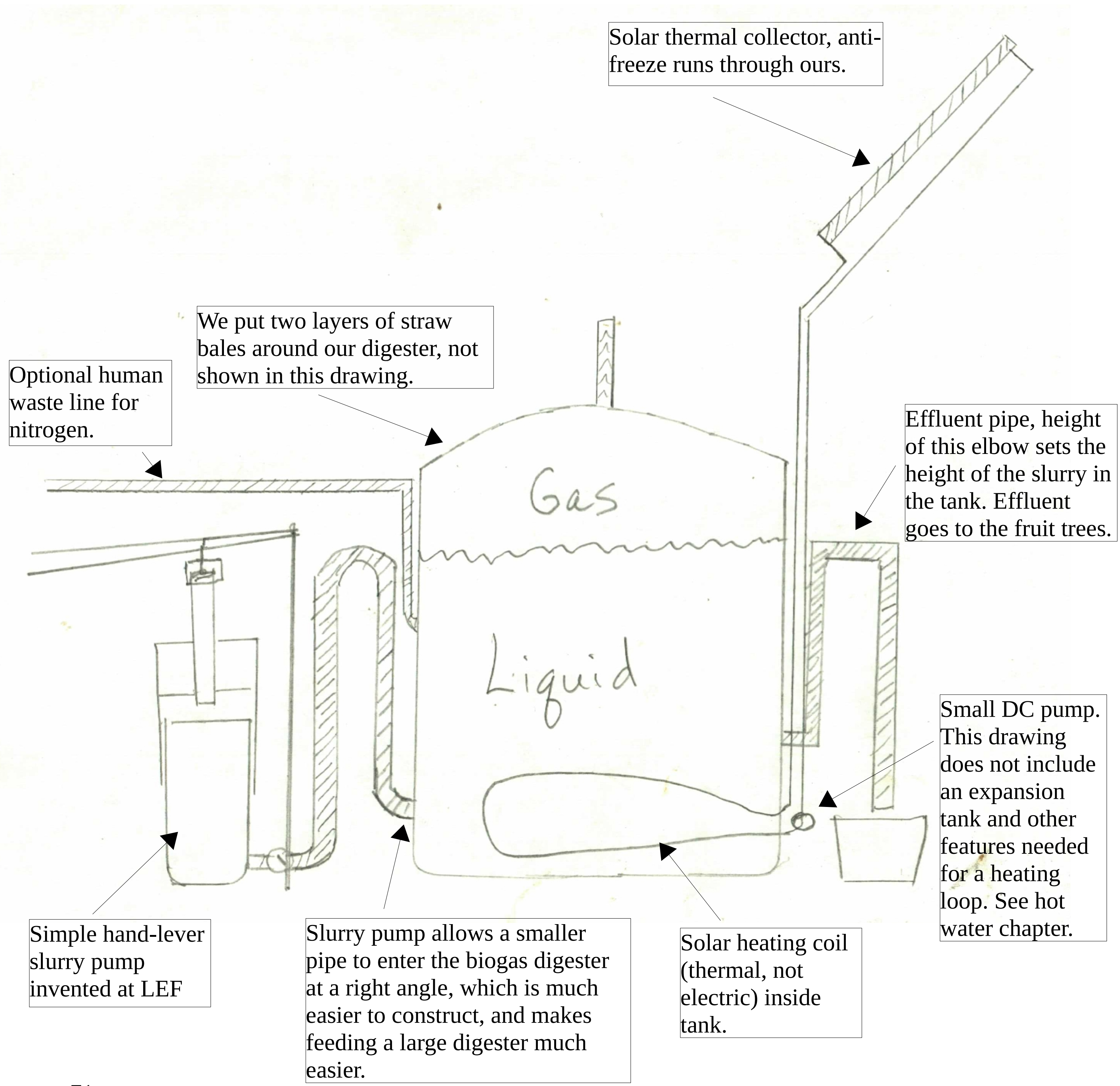
Particularly for small loads like this, the number of mechanisms we can add to our direct drive electrical system is very large because you can’t overload direct drive.

The disadvantage is that these pumps are very expensive in larger sizes. Building our own will make it cheap. Finding the right kind of tubing might be tricky. So far we planning to use a heavy (and not cheap) fiber lined hose from McMaster Carr.

Conventional Biogas Tank Design



Biogas Digester at LEF with Input Pump, Solar Heating Coil, and Heavy Insulation



Chapter 10 -- Woodgas, Turpentine, and Biogas, Farm Grown Fuel for Small Tractors

I have driven a lot of different kinds of tractors in my time. We had an old butane tractor growing up. The fuel lines on that one were leaky. Often as not, they would catch fire. The fires weren't big, but the tractor had a large pressurized tank that sat right over the engine. I always wondered if that thing might go off like an atom bomb some day.

The main workhorse on our farm was a Ford diesel. They taught me how to drive it when I was too young to reach the clutch or shift gears properly. My father would put the tractor in gear standing on the running board. He would put me in the seat, let up on the clutch, and then jump off. I would drive the tractor around in circles for hours in the hay field without changing gears or stopping. Then I would shut it down and climb off.

They taught me how to cultivate later on. That involves driving carefully through the crops with a cultivator behind the tractor that tills up the soil right close to the standing rows of seedlings. If you get it right, you can wipe out the weeds, and push a little shuffle of dirt right up next to the seedlings and cover the weeds there. Ideally, you can wipe out the weeds and leave nothing but rows of crops standing. It all rarely works like that.

I have a vested interest in good cultivation. As a youth, my peers were out watching movies and going about and socializing while I was working in the fields. The better the cultivation job, the less work there was to do. Even with a lot of very nasty herbicide, it seems our farm was often weedy. There we many, many days when the space above my knee and the tops of my feet got sunburned from sitting on a tractor all day long. To this day, I dream of cultivators cutting down those weeds and leaving pristine rows of crops behind.

It took me many years to realize that my father was not a good farmer, even though our family had been farming in that area for more than two and a half centuries. He was too distracted it seems. In my adult life I have tried to improve upon those old lessons. LEF is an organic farm, which means we use no herbicides, which means doing a good job of cultivating is very important. We are niche farmers growing seeds in many, many small patches. The rear cultivation rigs I grew up with are inferior to "under belly" cultivators that run right under the tractor. Now we have swapped down to an under belly one row system, and it's a dream come true for an organic small farmer. Even in wicked rainy years, even though we have many, many types of crops to contend with, the one row under belly allows for very precise weed control. There is something particularly satisfying about fulfilling childhood dreams.

The experiment at LEF is not necessarily to innovate new methods of farming or new energy systems. We are happy to use the tools others have created, if possible. Our role, so we have thought, is to see how the pieces might fit together in a post-industrial society. Can we produce enough energy on the farm to (mostly) grow our own food, plus export enough salable products to support ourselves? On a residential level, our energy systems have worked far beyond our expectations. Direct drive electric motors cover all of out needs for stationary mechanical power. Growing fuel to feed mobile farm machinery has been more challenging.

Reduce Fuel Needs First

Our approach to meeting needs for farm fuel has been similar to meeting residential energy needs in that we have a strong focus on minimizing energy needs first, and then we try to meet those reduced needs with some kind of renewable fuel. To reduce fuel consumption and simplify our equipment at LEF, we have downsized our machinery. Growing seeds is the economic backbone of our farm. Our small farm produces $15,000 to $25,000 USD worth of seeds (gross) each year, as well as about 85% of our food, on about 4.5 acres. To do that, and maintain the farm and orchards and whatnot, used to take 60 - 80 gallons of gasoline and diesel per year. The astonishing fact was that about 80% of our liquid fuel was used for mowing. Just mowing! Rotary mowers are energy intensive, and place heavy demands on engines, thus wearing them out. We have gotten rid of rotary mowers and replaced them with sickle bar mowers that are more efficient. Now that we are working with sickle mowers, we are down to about 40 gallons of fuel per year. Big improvement! That's great for us, because it means we will need a lot less homegrown fuel to keep the farm running. The sickle bar mowers are also quieter to run.

No-Till

In order to grow field crops with a minimum of fuel, we have used various methods, including no-till. In theory, no-till could use a lot less fuel. No-till also builds soil and reduces erosion risks. With no-till, one plants a cover crop, and then crushes (crimps) the cover crop to the ground. One plants through the straw mat of cover crop. I have seen some Amish farmers manage this process better than we. Rodale Institute has done a lot of work with no-till.

Our experience with no-till has been quite mixed. Sometimes it works. We have done spring no-till planting into crimped rye. We have done fall no-till wheat planting into mowed Sorghum Sudan. There are numerous limitations however. You have to have good weed management up front. If you have a lot of weed seeds in the ground, you are fighting a loosing battle. The biggest variable is rain. If the rains cooperate, no-till can work well. If it is dry when you want to plant, then weed seeds remain dormant, and sprout up later. That's a big headache. Rodale has developed (and some equipment manufacturers now make) an cultivator with strong blades that can slice under cover crop, and rollers over the blades to keep the organic matter in place. Yes, no-till tillage is a bit of a contradiction in terms, but what matters is what works. We have not built nor acquired such equipment.

Another issue with no till is timing, and how that affects your crops. You can't crimp winter rye too early, or it will not die properly. Fighting live rye in the crops you just planted is another headache. I can plant corn (and other crops) much earlier if I do some tillage. That last corn crop we did with no till was six inches tall whereas the corn next to it was nearly as high as my head. It was clear under those circumstances that the tilled corn was going to far outproduce the no-till corn.

Yet another issue we have faced with no till concerns crop rotation. Rye is the preferred, though not the only, winter cover crop for no-till operations. We grow wheat, and rye and wheat are close enough in relation that diseases can carry over. Thus we cannot maintain crop rotation with rye as a winter cover crop. With our diversified farm where many small crops need special attention, and with the various issues we have mentioned here, no-till has not been useful for us, and we do not use it much. A very small farm that relies more on hand weeding, or larger farms that have more uniform crops, might be better suited to no-till farming.

Strip Tillage

One form of farming that may be useful for energy reduction might be strip tillage. That involves leaving cover crop between the rows, but tilling a small strip where the crops actually grow. We have done some research and planning in that direction, but we do not know yet how well it might work with our style of farming.

Sheet Mulching

Sheet mulching is a great way to grow some crops. The caveat is that you need lot of sheet mulch. In my time living in a small city, I was able to collect enough leaves from the neighbors to sheet mulch a largish garden with leaves. I would lay down a thick layer of leaves in the fall or winter, and then open up holes or strips in the spring to plant. That works great for corn, tomatoes, melons, sweet potatoes, squash, and some other crops. Peppers will not grow that way, as well as some other acid sensitive crops. Sheet mulching also keeps the soil cooler, which is good for plants like white potatoes that like cool soil, but bad for heat-loving crops like okra.

I love sheet much gardening. It builds soil quickly, and overall is less work. Summer weeding is largely eliminated. Some permaculturalists speak as if that's the only option. The big limitation is finding enough mulch. For actual farming, you have to grow your mulch in place, which has led to no-till farming. That has benefits and limitations as discussed. Some organic farmers use massive sheets of plastic, even acres and acres of plastic. I would not do that, ever. That much use of disposable plastic is just wrong. We have done some sheet mulching at LEF when a local landscaper provides us with piles of leaves. But that only works on a very small fraction of the farm. We use other methods for most of our farming.

Reviving Older, Lower Energy Tillage Methods

Another tool that we are employing is a low-energy tillage implement that has about a dozen names. The most recognized name seems to be "disc tiller," which is not to be confused with disc, plow, disc plow, etc. A disc tiller is a heavy disc set at a sharp angle that rolls over organic matter at the top of the soil. It functions similarly to a plow, but uses a lot less energy. Disc tillers were used quite a bit 50 years ago, but not so much any more. I am not sure why. Certainly with big diesels and heavy implements, efficient tillage is less of a concern. We have an old disc tiller. Hopefully, as our bio-fuel program moves forward, we can help develop fuel efficient farming methods.

Tractor Engine Efficiency

The point is to reduce energy demand before you try to find a "sustaianable" energy source, and not just throw some form of biofuel at big engines. Another issue we have had to address in trying to run our farm on some form of biofuel is that of engine efficiency. Which tractor should we use? It's been quite a learning curve for us. Comparing Eyore, or old Ford 661 with a worn out 35 horsepower (HP) gas engine to other tractors, we have realized Eyore is very thirsty. He drinks a lot of fuel relative to how much work he gets done. Elmer is our Fordson diesel (a very well built 40 HP tractor from the 1950s) that will do twice as much work with the same volume of fuel as Eyore. One should note that most small cars have over 100 HP, and most pickup trucks, and a lot of SUVs, have over 300 HP. It takes a lot of energy to hurl vehicles down the interstate at high speeds, and we have gotten used to having enormous power at our fingertips.

Diesels are the norm for modern tractors, and they are more fuel efficient than gas tractors generally. But you can't run a diesel on woodgas, turpentine, or biogas. A diesel has to have oily fuel (diesel fuel or vegetable oil). For better or worse, older engines are slower and more durable, but older gas engines are less efficient. Modern gas engines are often much more efficient than the older ones, but the modern ones are often (not consistently?) less durable than some of the older engines. Generally speaking, higher compression engines are more efficient. Modern engines use overhead valves. That decreases the space above the piston, increases compression, and thus increases efficiency. The best balance of efficiency, durability and fuel choice get complicated.

Given our scale-down in tillage and mowing energy demands at LEF, even the modest 35 HP of an Eyore sized tractor is really more than we need. For our primary tillage tractor, we are now running a Cub Lo-Boy. That has a 14 HP engine that seems to be good mix of efficiency, durability, and availability (considering other folks might want to imitate us). It has a moderate speed, solidly made engine with no shortage of weight in the iron parts. That engine also runs at higher compression, thus higher efficiency, than most of its contemporaries.

To sum up, to maximize fuel efficiency of our farm, we have:

1) Avoided any dependency on 300 HP pickup trucks or large diesel tractors, and

2) Gotten rid off rotary mowers in favor of sickle bars, and
3) Used no-till and minimum tillage when we can, and
4) Switched to low energy tillage methods for when we need to till, including using a disc tiller, and
5) Carefully selected which machines we use based on efficiency and durability.

Woodgas

I first heard about running an engine on woodchips when I was a teenager. I was fascinated by the idea. I tried hard to research it, but I couldn't find much. That was before the rise of the internet. Going over the list of technologies we would need to run Living Energy Farm (LEF), woodgas was on the list. As an adult, far more information is available.

The first gasifier I built was the infamous "FEMA Gasifier." I say infamous because it's nearly impossible to get clean gas out of a FEMA Gasifier (Federal Emergency Management Agency). That gasifier was intended to be an emergency design that farmers or other people could build in the event that the energy supply was disrupted. I managed to make some smoky gas that would almost run a small engine. The results were not impressive.

When we started LEF, we had (and still have) an old, reliable Ford tractor named Eyore. It was born before I was, and has never been rebuilt. But it starts and runs quite reliably. We got a gasifier kit, and payed way too much for it. It was a complex kit, but in retrospect, had some serious design flaws. (It came from GEK in Berkeley, which is a moot point now anyway because all they are making are very expensive systems.) It took quite a while to put it together. We had a skilled technical intern on the farm at that point, and he was helping out. We built a solid steel frame and mounted the gasifier on the front of the tractor. I had spoken carefully with the supplier. They had assured me the gasifier would handle the 35 horsepower engine on the tractor.

It was a momentous day when we finally fired up the gasifier, and tried to run the tractor with it. We started Eyore one gasoline and warmed up the engine. We fired up the gasifier using a blower that draws air through it to get the fire inside up to temperature. And then we turned off the gasoline. In a moment the tractor engine started to sputter. I adjusted the air valves controlling the flow of air and woodgas going into the engine. And then the sputtering stopped. The engine just purred right along, running on nothing but woodchips! What a day that was. To imagine something as a teenager, and then realize the goal decades later is a fine feeling.

I got on the tractor and tried to drive it around. It took a few minutes to get used to adjusting the valves that moderated the flow of woodgas, but then it worked fine. I drove all over the farm, and showed everybody I could find. We went through that routine a few times over the next few weeks. Then came time for the big test. An engine idling or driving about at low speed is not using nearly as much fuel as an engine pulling a load. I put the bush hog (mower) behind the tractor, fired up the woodgas, and took it out to the field. Driving to the field was fine, but once I engaged the bush hog and pulled the throttle open, the engine would run for a bit, then cut out. Clearly it was starving for fuel. I went through that cycle again, and it was clear the gasifier was getting quite hot. After 15 minutes or so, the gasifier was smoking hot, the tractor was not running well on woodgas at all. I switched it back to gasoline, and drove back to the shed.

After it all cooled down, we opened the gasifier up, and the damage was extensive. The inner core was melted. A wood gasifier has to be sized to match the engine that is going to run from it. The assertion that the gasifier would handle our 35 horsepower tractor was wrong. That was a sad, sad feeling looking down into the gasifier and seeing lumps of melted and mangled metal.

We rebuilt the gasifier, and made another sturdy steel rack to mount it on a smaller tractor named Lucy. That took some time. Lucy had an 18 horsepower engine, so in theory she was better suited to the gasifier. Eyore is old and very worn, but also a trusted and reliable partner in farm work.

Lucy was a bit younger, also very worn, and not so reliable. Lucy didn't like woodgas much. She would run it, but complain the whole time. For some reason, I never could get the air flow to balance out and stabilize through any filter, and running with no filter is just not a good idea.

In spite of my teenage fascination with woodgas, it is clear that the technology has a lot of limitations. To make woodgas, you have to cut down trees. The biggest historical use of woodgas was in WWII, particularly in Europe. But there was also rapid deforestation, particularly in France, during the war. Starting a gasifier involves making a big cloud of smoke and carbon monoxide. That is unpleasant. I have never seen a cold engine start on woodgas, other than very small engines. I have heard others say they can do that, but it is another challenge. Wood gasifers have to be sized to the engine, and building a good one is a challenge. We more recently repaired the old gasifier and tried to run our Cub tractor on woodgas. It didn’t work all that well. At this point, I do not want to try to run a farm on woodgas. The liabilities weigh heavier than the benefits.

Turpentine From Pine Trees as Engine Fuel

A few years before we started LEF, I was talking to a friend of mine. He is an old-school machinist of the highest caliber, the same one who introduced us to nickel iron batteries. My description of him when I talk to friends is that he knows more about old machines than God. I am not sure if that's literally true, never having discussed the issue directly with the latter party, but my machinist friend he has been a huge help to me and LEF. I asked him one day to tell me how many different ways he could imagine to run a small tractor. I had no idea what I had just stepped into. There was steam this, distillate that, "tractor fuel" which was neither gas nor diesel. The conversation went on far longer than I anticipated. One intriguing option was pine sap.

On the farm on which I was raised, all the old southern longleaf pines had "cat faces" on them, big wide scrape marks left over from sap collecting. They scrape the bark off the tree from an area maybe a foot wide and five feet tall. They put a pan at the bottom and collect the sap that runs down. It's a practice dating back many centuries. The old term "naval stores" refers to the products made from tree sap that were critical to keeping the old wooden ships sealed and seaworthy. One of those products is turpentine. You heat up the sap and condense the vapor, and that is turpentine. Turns out turpentine burns in a very similar fashion to kerosene. A lot of engines made before WWII were made to run on kerosene and "distillate" fuel, and they should work fine on turpentine, so said my machinist friend.

The stately old pines I played under for my entire youth seemed to keep growing and thriving in spite of the "cat face" scrapes. Since that time, I have researched the matter enough to know that some form of pine, and indeed other resinous trees, grow in every ecosystem on the Earth outside of the most severe deserts or arctic regions.

Most everyone has heard of Honda motorcycles. Honda is a Japanese name, the name of a man in Japan after WWII who wanted to build motorcycles. He didn't have enough gasoline, so the first generation of Honda motorcycles was supplemented with turpentine fuel.

We have run a tractor on turpentine. It was dramatically easier than woodgas. I started the engine on our little underbelly tractor, and warmed it up running gasoline. Then I turned off the gas valve and turned on the turpentine. After a couple of minutes, we could smell the piney smell, and the engine just purred along as pretty as you please. I took it out to the field moved some dirt around. The performance was flawless. Very nice.

The big limitation of turpentine is making enough of it. We used store-bought turpentine for our experiements. It's quite expensive, and of no environmental benefit coming from industrial sources. We tried tapping some pine trees, and the results were not impressive. Are different varieties of pine more sappy than others? Perhaps those mature longleaf pines in southern Georgia are much batter suited for extracting sap than smaller Virginia pines. The bottom line is that we can't produce the amount of sap we need to make it work.

Biogas!

At this point, we have started running engines on biogas, though only on a test basis so far. The results have been encouraging. While it is challenging to get a gas engine to cut over to woodgas, we have been able to start biogas engines easily. We are capable of producing a lot of biogas at this point. We have put considerable thought and effort into setting things up so we can run the whole farm on the equivalent of 30 or 40 gallons of gasoline *per year.* For biogas to run our farm, that's how much we need, and it's clearly within our current production capacity.

Biogas is not pure methane. It has moisture vapor, carbon dioxide, and hydrogen sulfide in it. On our test runs, we were using raw, "unscrubbed" biogas, and still the engines ran fine. But you would not want to do that long term. We have started building scrubbers to remove carbon dioxide, water vapor, and hydrogen sulfide. It is a multi-step process.

The easiest way to scrub carbon dioxide is to bubble the biogas through a column of water. The carbon dioxide is absorbed in the water, creating carbonic acid. The problem is that the water saturates very quickly. We have built a recirculation system that pumps the water through the bubble column, the takes the water out, sprays it over a collector (to get rid of the carbon dioxide), then collects the water and sends it back to the water column.

We have set up a filter that removes water vapor by cooling the gas (wet rags around a metal pipe). A second stage on the filter passes the gas through rock salt to remove more moisture. The final scrubber involves passing the gas through iron oxide pellets (a commercial product, in this case) to remove hydrogen sulfide. On our test runs, we achieved zero measurable hydrogen sulfide. That's good, because that stuff would corrode an engine. In the future, we are going to collects homemade steel wool from out machine shop operations. Hopefully that will work well enough we will not have to buy iron oxide pellets.

We are now working on compressing the gas. We have an old belt-driven refrigeration compressor than can pump a few hundred pounds (run by a direct drive DC motor, of course). The proliferation of paint ball guns and pre-compressed pneumatic air rifles has created a market for high pressure scuba compressors. They used to be very expensive. Now the price range runs from a couple hundred up to thousands of dollars. Choosing the right compressor set up will be important.

We are working on the best way to feed biogas into the intake of our tractor. We have run biogas through cheap propane carburetors, but that is something that will need to be improved. Regulators that moderate the feed rate into the intake are easy enough to find. We are trying to figure out the best way to set that up.

Setting up a compressor, and proper pipes and hoses for high pressure gas is our task currently. Overall, using biogas as farm fuel seems a lot more attainable than the other fuels we have worked with. Depending on how things go (we have many projects...), we may make the farm fully energy independent in 2025, and or may take bit longer than that.

Growing Our Own Motor Oil

With any machine, lubrication is a problem. We have been pleased to realize that castor oil works as engine oil. Thus a post-industrial economy could grow its own lubricants. We have not done that at LEF, but castor oil remains a product grown on a large scale in other countries. It has been moved to the other side of the world because the castor beans are quite toxic. Castor oil is widely used as a lubricant. A scaled-down farm economy could grow it's own motor oil.

Draft Animals?

Why not use draft animals? They eat grass, and reproduce themselves, right? We have experimented with that on a small scale at LEF. We had a couple of oxen on the farm for a while. But we could not take the time to train them properly. And some cattle are better at going through fencing than others. Ours were pretty good at it. We finally had to concede that we did not have the time to manage them properly.

Draft animals are a fundamentally decentralized technology. Draft animals can have a relation with humans that is not highly abusive, though that is certainly variable. The big problem with draft animals is that they eat every day. Small tractors sit for many months at a time, eating nothing, though they certainly require more big-world infrastructure to make spare parts and what not. The bottom line is that there is no way we can feed all the world's populations with draft animal agriculture. Some of the world's poorest farmers still use oxen. Perhaps they have their role in other places, but not on our farm.

Biodiesel and Ethanol?

Biodiesel and ethanol have gotten a lot of attention, and government support. But these fuels put rich people's machines in direct competition with poor people's stomachs. Using food as fuel is just a bad idea from a social justice perspective. A more fundamental issue is that of the grade of energy. Starch to make ethanol and vegetable oil are both high-grade energy sources. It is always better to use lower grade energy sources when possible. Speaking as a largely self-sufficient farmer, producing bulk starch and vegetable oil on a scale to fuel engines would not be easy on a sustainable basis, if it is even possible. Industrial biodiesel and ethanol are bulk commodities produced in a centralized industrial manner. A post industrial world powered on biodiesel and ethanol would favor political centralization and abuse, and would only accelerate the genocide of working class populations on a global scale.

Steam

Draft animals are useful in some times and places, and the same can probably be said for modern steam power. Historically, steam power was the foundation of industrialization, though it came at a price. Modern steam turbines keep grid power running, and that also comes at a high price.

But what about small scale steam for small farming? Maybe, but it’s not easy, and probably not scalable. The easiest way to get a steam engine is to convert a gasoline engine. A gasoline engine has the same basic structure as a steam engine, which is to say an expanding gas pushes a piston in both cases. It is possible to take an ordinary gas engine and make it run on steam. You modify the cam shaft that opens and closes the valves, adding new lobes. With this modification, the intake valve is open on every down stroke of the piston, and the exhaust is open on every up stroke of the piston. Then you push pressurized steam into the intake. It’s not terribly difficult, and it does work, but it’s not every efficient. And maintaining lubrication is challenging. We have done this at LEF.

Steam engines are actually easier to build than effective boilers. To do real work with a steam engine, you need a substantial volume of steam at a substantial pressure. That translates to a lot of metal, and someone who knows how to put all that metal together. Again, lubrication and corrosion issues come into play. Long ago, steam power was refined to a high science. Studying the old manuals would be wise, if one wanted to go in that direction. For LEF and our mission to find solutions that could be applicable on the larger scale, building boilers and steam engines does not seem scalable in a practical sense.

Beware that there are a number of steam scams on the internet. They involve things like “green steam,” which is a bunch of shiny, modern-looking machines whizzing about, reputed to produce lots of horsepower. It’s a fake. Without a strong supply of high pressure steam, and enough metal to contain all that pressure, you are not making lots of horsepower.

There is an option that I would call emergency steam. That would involved a steam generator. One could use a coil from an old pressure washer. That would give you wet steam, which would need to be cleaned up. That could be run into a converted gasoline engine, and it could produce some power. It would be potentially dangerous, and abysmally inefficient. There are also manuals from long ago about small boilers that were built in makeshift mining camps and what not. Based on the information we currently have at our disposal, we are not pursuing these options for farm fuel.

What Constitutes a Sustainable Fuel for Farming?

The whole question of what constitutes a sustainable level of mechanization is a complex one. Answering that question at the societal level is completely undermined by the fact that the U.S. is a society of mechanically ill-informed people. That is a big part of the reason that so many of our "environmental" projects are getting misdirected. People just don't know how our current systems work, much less how much more efficient systems might work. We are left at the mercy of corporate profit.

The industrial agricultural system is in trouble in a lot of ways. What replaces that system is a complex question. Certainly, growing food is a revolutionary act, particularly at this point in our history. The simplistic answer is that the closer our methods are to older, more "natural" methods, the better. Growing food at the level at which one can handle the process with simple hand tools is noble, but some more technology is going to have to be involved.

The simplest answer is not always the best. I have some friends who live without electricity at all. I applaud their providing a counterpoint to modern technological foolishness. They use candles. Many poor people in the world use kerosene for lighting, but that is smoky, a fire hazard, and a petroleum product. The simple answer for people living at low population densities is not the best answer for millions and billions of people. Small number of people can hunt wild game, use products straight from the forest, and use bees wax candles. When I look at large numbers of people wanting and needing lighting for long periods of time, I think the lowest environmental footprint is achieved with small nickel iron battery sets dedicated specifically to lighting and electronics, as we have discussed here.

What's truly sustainable as regards global food production? Certainly, there are as many localized answers as there are farmers. That said, it's clear that the massive, industrial food systems we have now are not sustainable, or ethical. Draft animals might be useful in some times and places. But we need something beyond that as well. Of course, the overwhelming problem at the moment is that very few people are convinced of the need to simplify our lifestyles at all, much less to the degree that is almost certainly required. It's truly a tragedy on a monumental scale. If we downscaled thoughtfully, in living and farming, we could improve the quality of our lives in the process. Sadly, it seems all but inevitable that we are going to hit the wall hard and then try to figure it out.

The term that comes to mind as regards supporting large numbers of people is "intermediate industrialism." For farming, we need small-scale machinery that can support us more effectively and efficiently than either massive diesel machines, hand methods, or draft animals. On a larger scale, that would look like well-insulated buildings, many more people involved in food production, people living near where they need to work so they do not drive, durable tools like nickel iron batteries for lighting, and small farm machinery.

I really love the small farming setup we have at LEF. It's efficient, and downright fun -- well, sometimes anyway. Just like with housing, by far the most important part is making sure the systems are well designed rather than just trying to throw "renewable" energy at traditional, energy consumptive systems.

I know a lot of people might say that we should plan to use fossil fuel, but less of it. There is a monstrous problem hidden in our energy system that few people consider. The first successful commercial oil well Pennsylvania in the mid 1800s was 70 feet deep. Though oil prices are very low right now, that does not change the fact that all the oil that is left is very deep. The decline curve of oil production will come, and it will be slow at first. But at some point, we may loose the technical capacity to reach oil many thousands of feet deep, on land or under the ocean. There will with certainty be a precipitous drop in oil production, though pollution and climate change may make their presence known in a more dramatic way before that time comes. My point is not to predict the future, but rather to point out that having easily accessible fuel sources that truly are environmentally benign, if we can find such a thing, is highly desirable, even if those sources are quite modest. A little goes a long way on farm. We cannot count on the coming changes happening slowly.

I have no illusion about producing biofuels on a scale to support people commuting to work in private cars. That will end by the will of the laws of physics. But supporting modestly scaled machinery on a self-sufficient farm seems a more attainable goal.

We could imagine some idealized vision of "re-wilding" and living more simply like our ancestors. That would only work if billions of people die. Even from the perspective of valuing wild nature, a human die-off is nothing to wish for. Apart from the unimaginable horror such a set of events would represent, it would almost certainly mean the destruction of most of what is left of the wild lands and animals still living on Earth. We desperately need to scale down gracefully. The intelligent use of machines is an absolutely critical part of that soft landing. Re-wilding, candles and gardens are romantic, and that they should be. Industrial "renewable" energy is currently doing more harm than good, mostly because it is allowing us to ignore the addictive and destructive nature of modern consumerism. The intermediate road of using appropriately scaled tools to support a transition to a sustainable world is the wise path. One day, one community will make DC motors. Another will grow castor oil. Another will make solar hot water panels. They will all grow food. It's a better life than the one we have now.

The older generation -- my generation -- will never embrace that vision. I argue with them, but I know it is futile. They speak in panicked tones about climate change, but they are not going to give up their industrial energy systems, "renewable" or otherwise, no matter how massive or obvious a pile of information accumulates to show the error of their ways. Conservatives are not the only ones who deny science. Many people will speak in panicked terms about climate change and extinction while they continue to bolster their privilege, and when you march in the street, they will put themselves at the front of the parade and declare their solidarity. Their goal is to draw you into their ideology that supports aggregated energy systems, centralized production, and the value of the current housing stock. Yes, the planet is being sacrificed to support the resale value of current housing. We need a better answer.

We have to build the future. If you want to engage in direct political activism, then that's a good thing, not a bad thing, always. The shape of our future will be determined by the shape of our economy and its relation to the Earth in the years to come. You are empowered to build a better world yourself.

Chapter 11 -- Growing Food

There are as many ways to grow food as their are people who grow food. And there is nothing that proves the maxim "you learn by doing" more so than agriculture. There are lot of theories and ideologies out there. And lots of people who want to present themselves as experts without getting their hands dirty. It's all fine and good to look at many ideas, but there is no magic technology that makes farming into something other than a product of focus, honest work, and experience.

A poor gardener plants, their crop fails, and then they shrug and say "I am a poor gardener." A good gardener plants, their crop fails, and they plant again. Again their crops fails, and again they plant. When they finally make a crop, everyone says "What a good gardener you are!"

Food Production, Food Self-Sufficiency

I have been intrigued to read about human societies that live in tropical climates that grow most of their food with horticultural methods, that is, on trees. At Living Energy Farm, we grow as much food as we can on trees. But in a temperate climate, the bulk of our calories will always be annual grains, pulses, and root crops. Nothing wrong with that. At LEF, we grow most of our own grains, grind them with solar energy, and cook them fresh with solar cookers or biogas. It's the best food I have ever eaten.

The single biggest aspect of food self-sufficiency is to eat what you grow and grow what you eat. This seems obvious, but for most people, it is a big adjustment. Organic growers take for granted that they must battle disease and insect pressure when they take crops from New England and grow them in the south. Our diet is based on annuals and perennials that, in healthy soil with good organic matter, can grow without sprays, integrated pest management, trap crops, compost teas, or labor intensive interplanting. We do use row cover sometimes. (That’s like a very thin white sheet that lets sunlight through, but stops bugs and pests.) Also, we are lucky enough that our fields are surrounded by wild lands which provide habitat for all manner of beneficial insects. Other growers may need to provide this habitat themselves.

It is spiritually out of balance to eat foods from very far away, especially animal products, and not so much because of transportation costs. Rather, when we eat from far away, we can do great harm without ever even knowing it. If we hope to live long on this planet -- and we haven't yet -- then we have to remain spiritually connected to it. The land will feed us, but we must pay attention.

Before we started LEF, I had many ponderous discussions about whether or not organic agriculture really could feed all of humanity. Having moved much closer to full food self-sufficiency, that is no longer a concern. Organic agriculture can easily, without question, feed humanity, and do so sustainably, provided we eat a plant-based diet. That's not a political statement, at least not in this context, but rather a practical one. Food self-sufficiency requires some talent in the kitchen, but the results are most satisfying. Growing enough grains, vegetables, nuts and fruits to feed ourselves is not hard at all. Having some mechanical assistance makes a big difference, of course.

Food from Trees

Growing food on trees is arguably the most benign form of agriculture. There is no erosion whatsoever, soil is built, and the large root systems of trees can tolerate much, much more variation in rainfall. Tree based food -- horticulture -- can be extremely efficient once established.

I love growing fruit and nut trees. I published a pamphlet entitled *Perennial Food, Growing and Propagating Fruits and Nuts for the Home Grower*. That pamphlet is now a small book that has been revised many times. It is online at http://conev.org/fruitbook9.pdf Another useful resource is a 5 hour video produced by myself and Michael McConkey, proprietor of Edible Landscaping (.com). That video is titled *Planning a Home Orchard*. The link is https://ediblelandscaping.com/products/planning-a-home-orchard-video?_pos=1&_sid=2d6792d0d&_ss=r

Those works have a regional focus, that being the mid-Atlantic of the United States. I hope the words I write here will have further reach than that. The reader should be aware that with fruit, just as with vegetables, you have to figure out what grows well in your area. Growing food from trees is very different than growing fruit for sale. If you go to the grocery store and buy a Yada yada apple, you shouldn't expect to grow those at home. The nursery trade is mostly made up of honest people, but you can't just buy the trees in the popular catalogs and expect to grow much. The tree food that shows up in the grocery store is the product of modern chemistry. A lot of insecticide and fungicide is often used. Standardized industrial methods used to produce uniform looking fruit. The bottom line, especially for horticulture but also for agriculture in general is that ***you need to choose regionally adapted varieties.*** Industrial food production works by standardization of varieties, methods, and heavy chemical inputs. If you try to grow the same stuff you see in the grocery store, it will not work. You will end up with an unproductive mess, and it will take years to realize that, especially with fruit and nut trees. Particularly in the humid parts of the U.S., if you plant the wrong kinds of trees, you can plant lots of trees and end up with nothing.

At LEF, by far our biggest tree-born food is persimmons. Americans are not accustomed to eating them, but at LEF, we eat a lot of them. The fresh ones are very sweet, the dried ones taste like a natural form of jelly beans. The Rosseyanka and Nikita's Gift varieties, both Asian-American crosses, are our favorites. We mostly dry the Nikita's Gift persimmons. The Rosseyanka will last all winter in outdoor temperatures (we keep ours on trays on a covered porch) without canning, freezing, or drying. Nice. We have more recently found some more Asian-American cross persimmons, those being Zima Khurma, Kasandra, and Mikkusu. The Zima Khurma is very much like the Nikita's Gift (fantastic!). The Kasandra is early and very sweet. The Mikkusu is slow to ripen. It is sweet, but may retain some astringency in the skin. Zima Khurma and Kassandra are now on the short list of favorites. These Asian - American crosses are more cold tolerant than the Asian (kaki) varieties, and supply us with significant amounts of food.

Filberts/ hazelnuts are the easiest nut to grow. They can come into production more quickly than other nuts, and do not need a huge amount of space. In humid areas, one needs blight resistant varieties (such as Gene, Yamhill and Slate), not the commercial varieties. We grow some pecans as well. Any and all nuts need to be protected from squirrels or you will never eat a nut. Plant your nut trees where there is *not* a bridge along tree limbs from the forest to your trees. Squirrels on the ground can be discouraged more easily, especially if a talented dog is involved.

Blight resistant pears are reliable bulk producers, but they must be fire blight resistant, not the varieties you see in the grocery store. Jujubes are an Asian fruit that is easy to grow, and easy to dry. It has taken a while to learn which jujubes work best. For fresh eating off the tree, Sugarcane is best. It is sweet, juicy, and a reliable producer. I used to recommend the folks plant Li variety for drying, as it is a reliable producer of large fruit. If you get heavy rains at harvest time, however, it will rot before it ripens on the tree. Tigertooth (also known as Silverhill) is a later producing jujube that works great for drying. It stands up to bad weather much better than Li. Tigertooth can easily and reliably be dried whole.

We also grow muscadines, and southern grape that is extremely disease and drought resistant. We grow some northern adapted pomegranates (Salavatski, Asperonski). Fuzzy kiwis will grow much farther north than most people realize. They can be eaten through much of the winter without canning or freezing. Hardy kiwis will grow in very cold climates. They are tasty, but do not keep the way fuzzy kiwis do. All of the kiwi family likes good soil and are not highly drought tolerant.

Figs are easy to grow, highly drought tolerant, and super tasty if you live in an area that is warm enough. Pawpaws (asimina triloba, not papaya) have gained some popularity, but they of limited value as a food self-sufficiency crop because they cause digestive upset for some people, are highly perishable, and they cannot be canned or dried. Bulk freezing is common, but we do not do that at LEF because it is too energy intensive. There are a lot of berries that grow in many climates, including small spaces. We grow strawberries, raspberries, blackberries, blueberries, juneberries (aka sarvice berry, service berries, saskatoon), and goumis. The primary limitation in using berries as a food source is the time involved in harvesting. We grow apples, but they are always gnarly and get made into apple sauce. We grow peaches, but the productivity is variable. They attract a lot of insect damage that is not easily controlled without very toxic chemicals. Sour cherries do okay in our climate, though not great, and not for a long time. Sweet cherries and plums are not reliable producers in humid climates.

Urban Gardening, Growing Food with Little Space or Time

Gardening in urban areas can be different than in rural areas. In urban areas, it will make more sense to plant what augments your diet in a complementary fashion (do you like tomatoes or greens?), and avoid space-consuming crops like sweet corn. In urban areas, at least around here, people throw out a lot of organic matter. There are lot of complex theories about gardening and soil health. One thing is for sure, there is no such thing as too much organic matter. The abundance of leaves, grass clippings and what not can provide for a form of gardening that is super-easy called sheet mulching. With sheet mulching, you can lay down thick layers of organic material, and plant right through that material. I have used leaves extensively this way, and gone for years without tilling at all. It is very easy, effective on many crops, and very time efficient. The only caveat is that acid intolerant plants like peppers cannot be grown this way. Tomatoes, corn, squash, okra, melons, and many other vegetables love sheet mulch. Some brassicas like it better than others.

Cover Crops and Fallowing to Build Topsoil

If you are not in a position to import large amounts of organic matter, you need to grow it in place. Cover crops are the most essential practice that separates organic farming or gardening from chemically based "conventional" agriculture. The basic practice is that you never leave soil exposed for any length of time. Rye is a very cold hardy grain that will grow through the winter in many areas. We also use tillage raddish, vetch, lots of clover, sorghum sudan, and other cover crops. There is a lot of good information available about cover crops from other sources, so we will not review that in great detail here. Different farmers using different techniques will need varying cover crops. Certainly finding ones that fit your methods is necessary. Some cover crops die more easily than others when cut or crimped at planting time.

Improving Disease Resistance

As seed growers, we have come to appreciate what a difference it makes to start with seeds selected for performance under our conditions. Just a few generations of selection can greatly increase disease resistance in cucurbits, for example. We are lucky to be connected to a network of seed growers in the region who are selecting every year for high-quality genetic material. You can learn how to save your own seeds and buy from regional growers in your area.

Food and Food Processing

Our plant-based, homegrown diet is focused on a few staple crops, which store easily and provide the bulk of our calories. These crops are corn, wheat, beans, peanuts, spring potatoes, and sweet potatoes/winter squash. Corn and wheat also provide the bulk of the calories for our ducks, which provide us with eggs. We also grow all of our vegetables. Some of these we get as a by-product of growing vegetables for seed. But we also grow lots of veggies to eat fresh, or preserve for the winter.

We ensure a supply of vegetables year-round we use several methods of food preservation, including season extension, fermenting, canning, and drying. Season extension is the easiest method of "food processing." We extend the fresh picking season by doing multiple plantings, using row cover, and choosing cold-hardy and disease resistant varieties.

Fermenting is kind of like season extension. It doesn't put the food in suspended animation to be stored indefinitely like canning does. But it is easy and so very tasty. If you have a root cellar or extra refrigerator space, it can store for several months. Our favorite foods to ferment are cucumbers, green beans, winter radishes, and carrots. Cabbage of course is excellent fermented.

Canning: We do boiling water bath canning for high acid foods, and pressure canning for low acid foods like sweet corn. For boiling water bath canning, we do a whole lot of tomatoes and fruit (pear sauce and peaches mostly).

Drying: We have a lot of capacity to dry food as a side benefit of our solar hot air-based heating system. The first year we had our dryer we tried drying everything we grew. We learned that a lot of vegetables don't retain much flavor when dried. Now we are more discerning. Our favorite vegetables to dry are peppers, eggplant, okra, and green beans. Tomatoes of course are very tasty but also difficult to dry with a solar dryer, as they mold easily overnight. Almost all fruits dry easily and are delicious, especially persimmons and pears.

Resources

We are very fortunate to have three local gurus of sustainable food production, who have decades of experience growing food in central Virginia, and have all written books on the topic. These women are Ira Wallace (Vegetable Growing in the Southeast), Cindy Conner (Growing a Sustainable Diet), and Pam Dawling (Sustainable Market Growing). Pam's book is an especially useful reference because it contains details down to planting dates and varieties best suited for our region.

In the world of perennials, an excellent local resource is Michael McConkey and his nursery Edible Landscaping (www.ediblelandscaping.com), which specializes in low-care perennials for the mid-Atlantic. Alexis' booklet, Perennial Food, is super useful as well and available at http://conev.org/fruitbook9.pdf.

For sourcing seeds, we recommend Common Wealth Seed Growers (https://www.seedwise.com/farmers/18/common-wealth-seed-growers) and Southern Exposure Seed Exchange (www.southernexposure.com). SESE also has organic planting stock like alliums, white potatoes, and sweet potato slips. If you're not certified organic, you can get planting stock from a local farmer's cooperative like Southern States, and it is much cheaper.

Of course there are piles of other books about organic food production out there. Useful books by non-regional growers are The Resilient Gardener by Carol Deppe and The New Organic Grower by Elliot Coleman. I especially like the section in Coleman's book on farm-grown fertility. Carol Deppe's book is focused on the northwest. It is especially useful on the topics of seed selection and breeding. Her book is also excellent for understanding all the different kinds of dry corn (flour, flint and dent) and the best ways to cook them.

Hundreds of pounds of persimmons, harvested fall, 2019. These have high caloric/ food value, much higher than other fruits, and dry easily.

Chapter 12 -- Calling Down the Gods of Our Ancestors

Human cultures evolve from the ground up. Ecological circumstance sets the stage for the kind of production or economy a society has, and that process dominates the evolution of the rest of what we call culture. If everyone understood these basic facts, everything would change.

Some aspects of human cultural evolution are intuitive, some are not. It is intuitive to recognize that localized economic power would support decentralized political power. Democracy and corporatism are incompatible. That's why American politics are going crazy. It is in the rational (not moral) interest of people with a lot of money to destroy democracy. Democracy impedes their privilege and taxes their wealth. If everyone understood human cultural evolution, the massive corporations that dominate our world and our politics would evaporate. Many people would agree I am sure that economic localization is a good thing. The difference is the amount of weight given to these facts in the choices we make. We are fully empowered to change, even dominate, the evolution of our own society from the ground up, if we understand the supremacy of material factors over our cultural evolution over time. Most people choose to care about other things most of the time because of the dominance of mentalism.

A huge gap between the possible and our current economy has opened up. By choosing intelligently among the technologies that can serve us, we can support ourselves with an entirely different economy. We have been aggregating solar panels and other "renewable" energy sources as a means of supporting existing power structures -- power taken to mean energy as well as political and military power. We do not need grid power, and we do not need giant corporations to feed us. Producing electricity in our boiler economy is the single largest source of greenhouse gas. We can feed ourselves.

A barrage of facts about climate change has done little to change anything. Many people are in denial. And our leadership has betrayed us. They continue to support aggregated energy systems. In doing so, they are unwittingly supporting political centralization. It is no accident that those of us who advocate sobriety and justice are pushed to the margins.

Get it. Half of the species on the planet have died in a human lifetime. I don't care if you call the Sacred Earth a divine creation or "only" the product of four and a half billion years of evolution. Either way, it is sacred, it is being destroyed, and it is our obligation to defend it. They will call you crazy. That's fine. Crazy people are always the first to see an approaching danger. The religions of power-centralized states have created fatherly gods that reside in unearthly places. Look around you. The sacred is manifest in the living world around us. The spirits of pre-imperial cultures lived in the bushes, in the forest. That's where my God lives. The living Earth is Sacred, and we should respect it as such.

If you want to understand human social behavior, a systematic, scientific approach is necessary. The psychology books are full of cute insights into individual quirks. Mass movements are not a collection of quirks. They are directed. The reality is that we live in an age of massive accumulations of wealth and power. And that power prefers ignorance. Even under the guise of democracy, especially so one could say, we are taught to want to be on the winning team. And now if the winning team votes for a tree stump as leader, the domesticated humans follow along. We skitter about like anxious mice. But evolution, of the biological kind anyway, moves like a great yawn. Our current course has us evolving toward something like mole rats. Mammals, but not the intelligent being that is the wild human we are now. We are wild humans wearing the clothes of the domesticated human. Anthropologists understand that. Many presumptive writers make the claim, and then return home to the Roman property code.

The roles play out in history. There is a story from Holocaust literature -- the stories from the survivors of the death camps of the Nazi regime in Germany. They were riding on the train, one group of them. The Nazis were insistent, but respectful and calm, lest they provoke a rebellion from their victims. But then the village crazy woman, the one for whom no one had much respect, was climbing the walls of the cattle car, screaming about gas chambers.

So it is, among those who see a darker future, we are an anxious lot. You will scarcely hear me quote anyone who called themselves a philosopher, but there was one little phrase that I find useful. "Cynicism of the mind, optimism of the will." That one I have never let go of. I want my mind to be forever unrestrained. Defy the demons, of the hell of our own creation, of the past or future, hide nothing from me.

As an organizer, there is but one rule. Without enough people, you lose, no matter how right, smart, moral, or dedicated you are. With enough people, you win. But what of this great age of indulgence? The industrial mode of production provides comfort beyond measure, indulgence and addiction I cannot touch. I offer them home grown grain, healthy food and sweet fruit, and they want candy, and blood clogging grease. They make up reality, each and every day. The false prophets abound, the charlatans, making up nutrition and science and mountains and mountains of bullshit. I speak, I speak a lot. Few listen.

Brass tacks; It's going to get worse. The virus is real, and we can't stop it, not quickly. A lot of people are going to die, and a lot of what is left of wild nature is going to die. The term “revolution” perhaps will have to take on another meaning -- re-evolution. Can the coming generations let the natural world recover? I don't know. But in the immediate sense, power accumulates, and money makes money makes money. *Science and the State in Greece and Rome,* Thomas Africa. In the early empires from which we came, they embraced science, then they rejected it. I have known many people of many different political persuasions for a long time. Now many of them reject the most basic tenets of rational inquiry. My conservative friends tell me there is no proof of evolution. My liberal friends tell me that grass fed beef is good for you. The bottom line is that there we endorse the “science” that supports our privilege, and a real social science that would explain our own behavior in the context of material culture has yet to be born.

Collapse? Depends. If you are poor, yes, now and getting worse. If you are rich, maybe never, surely not soon. Did you know that almost all of humanity is poor? They are invisible. Never mind an elephant in the living room. That's more like a planet that we just don't want to see.

I use the word “contraction,” contraction of the industrial economy. That is as inevitable as gravity, evolution, and purposeful ignorance. Give it up my friends. Trying to tell the privileged to be kind to the Sacred Earth, passing policy is long past. And now you cut down the sacred trees to put up your solar panels?

Okay, here's how it works. Contraction and suffering of many things is inevitable now. The virus is here, and there will be more to follow. We have to imagine the world we want, and build it.

More than anything, *we have to return agency to the hands of our follow humans*. Real democracy is not political. Politics are built on economy, economy is built on ecology. There is nothing more abhorrent to the privileged than the science of human behavior, and most of our leftist leaders are privileged enough to toe that line. They do not want ordinary people to know that we create the future with our hands. They get away with it because leaders across the political spectrum turn the world upside down every day with every word they speak. They focus on the ideas and dramas of the educated and wealthy classes, and ignore the work of ordinary people. Real democracy means you have your hands on the soil and machines that make your life possible.

You want a democracy in the future? Make sure people have economic power. Always, pull it down, the power that is. Whatever you build, buy, sell, trade, grow, or make, pull it down to the lowest level. When the working people understand that agency is in their hands, then the centralized powers will fail. Sure, they will make wars, and God help us, more pogroms and race-baited riots. I wish I could stop them, here and now. But we can stop them over time. Pull it down.

Your God lives in the trees around you. You must learn that. You must teach it to your children, and never, never let them take agency away from us again. You build the future with your hands, your own minds. It doesn't matter who wins the ball game today, it matters what we build over time. Give up their poison food. Give up their future cannibalism. Do not eat your children's future, our kin on this Earth. The ancients had a different covenant with the wild. And most of all, stop the lying. Stop telling your children to play nice while you hide in your Roman palace.

Peace grows in a field. Study the anthropologists. I know a bunch of them were racist, sexist pigs, but the people they looked at were not. They were wild humans, not empire builders. The wild humans were visceral. Many were egalitarian. Most of all, their Gods lived in the bushes. Eye to eye with the deities.

Our God lives in the trees, on this Earth, not in the sky. You have to give up your Roman palace, or it will be torn down around you. Few will listen, I know that. If I could stop the great cataclysm, I would, at any price. But my tempered steel determination, made of love or hate is of no consequence without enough constituents. They want cheese pizza, congealed of the blood of their own children. They want to keep their Roman palace, built on the bodies of dead slaves. They want to keep the Gods in the White House, on the screen, in the sky and anywhere but in the tree trunks to be touched by human hands. Those trees are sacred. Never forget it.

The words are cheap. We are global citizens. We are agents of our own evolution. The path of grass-fed solar panel-fired electric cars is the path of human mole rats. Study the anthropologists. Witfogel. He said long ago that the hydraulic empires, the early empires that were built along river valleys, were tyrannical in a greater degree because of the centralization of the economy. Many since then have told us that our own behavior, our own moral judgment, is rooted in those economic relations. The Romans built the first liberal state, where anyone could become a Roman citizen. The first race-tolerant state that venerated life, even as they slaughtered in unprecedented numbers. And now we have inherited that same trick, the trick of hiding dependency, power, and oppression. Apartheid failed because it was black and white. Class division never fails because the oppressor is hidden. And now even the most compassionate order their little boxes from the corporations -- I will not say the name of Satan on Earth. That is Satan, the evil incarnate, who has taught you to ignore your economic dependency on the great corporations. If we are dependent for our food and vital needs on people who know little and care less about us, we are their slaves. Get it.

Break your chains of slavery. I don't give a damn who their computers elect, feed yourself. Teach yourself how to make your own energy, how to be free, independent, wild humans who worship that which is sacred, the living Earth around you. Most of all, organize. The whole history of humanity, past and future, can be summarized in a single sentence: The organized enslave the disorganized. Leadership is like digging roots, it's a job. You don't get to choose whether or not you are dependent, you only get to choose on whom you are dependent. And we, all of us, have been choosing corporate cannibal pizza made of children from the future.

God lives in the trees. The living Earth is Sacred. I came here to tell you these things. Do not focus on the ones who will not listen. Many will die. Life will continue, and you must work with every cell in your body to never accept the dying. It is not a philosophical stance to watch the Earth die. The systems will go haywire, far worse than we can see now. The great forests will turn to deserts, and rain will fall in the deserts. The ocean currents drive that process, and they will change. The human mole rats will try to take their grass-fed cattle onto those new grasslands, they will push and push and push, celebrating ignorance and the winner of the game, until they turn this Earth into a molten, lifeless Venus. No, that will not happen soon. But you must understand, the physical changes coming now are a symptom, not a disease. The disease is directed ignorance. We must resist that, we must try to build as much as we can a movement of people who reject privilege, who respect the leaders who empower a conscious dependency among people who we can touch with our hands so we are empowered to reject the chains of slavery tying us to our corporate masters. Never let them feed you, these people you can never touch.

The Earth is sacred. Worship her. Quietly, loudly, in your mind and heart if nowhere else. Fight for her. Let the tradition fall down through the generations. This is a new covenant, a new agreement between us and the Earth. We are not the hunters of big game now. We are the keepers of the sacred seed, the seed of empowerment, true science, connection, respect for the God who you can look in the eye.

This is the new covenant, a new agreement between humans and the sacred. Keep it, teach it. Focus on what we can do, what we can save, and who will listen.

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