DC Microgrids
Home Power With A Dramatically Reduced Financial and Environmental Pricetag

Alexis Zeigler

Living Energy Farm is an educational and technical development project in Virgnia, USA. We have developed a DC microgrid system that provides services that are similar to AC electrical grid power, but at a small fraction of the monetary cost and carbon footprint. Though the service provided is different than conventional AC power, the overall level of comfort for end users is similar. This document outlines what we do and how we do it.

AC power is based historically on the availability of industrial steam boilers. AC power can travel efficiently for long distances down transmission lines. The weakness of AC equipment is that it needs constant, unvarying voltage. To run AC equipment from renewable power sources (wind and sun in particular) requires expensive and complex storage schemes in order to maintain a constant power supply.

DC electricity does not travel well over long distance transmission lines. However, *DC equipment easily tolerates changes in voltage and power supply in a manner that is very different from AC equipment.* This characteristic of DC equipment makes it well suited to sun and wind power sources *in the absence of expensive battery storage.* Because of these differences between AC and DC equipment, DC microgrids are probably best constructed on a limited scale. Large populations would need multiple DC microgrids to provide adequate service.

Solar photovotaic (PV) power is fundamentally different from centralized, boiler-derived power. Boilers and industrial steam turbines have to be large scale be economical. PV is modular. It can be built to any scale, large or small. Trying to make PV output function in the same manner as boiler-derived power diminishes the potential serviceability of PV power, and dramatically increases costs. DC microgrids make use of the inherent strengths of PV power instead of trying to make it perform like boiler power. In doing so, DC microgrids are cheaper and much more effective than trying to imitate traditional AC grids.

The following is based on the experiences of Living Energy Farm (LEF), a community of people who live without fossil fuel or grid electricity. LEF is a fully operational and economically self-sufficient farm and community, not just an idea. LEF was built at a very modest cost. The approach we have used can be applied all over the world, even in communities with very little money.

LEF is unique. We live and earn our living using the tools and social organization that we espouse. We experience the benefits and limitations of our own ideas, and we improve them, day by day.

The Living Energy method of employing DC microgrids is characterized by the following:

1) Multiple DC power sources provide power to multiple end uses. A DC microgrid is not one system, but many. There is no such thing as a system-wide power outage.
2) A DC microgrid is an integrated village energy system operating with extreme efficiency compared to either conventional grid power, traditional off-grid design, or other modern microgrid systems.
3) DC microgrids float with fluctuations in power supply, and are thus ideally suited to renewable energy (wind and sun). Energy is stored in forms other than electricity, thus making the system much cheaper than other alternative power systems.
4) The DC microgrid employs very durable technologies, using machines and storage devices that will last for decades with little maintenance.
5) DC microgrids are the *only* power supply scheme that breaks the tradition of supplying round-the-clock AC power. Instead of focusing on historically inherited, inherently inefficient energy use schemes, DC microgrids focus on providing *services* rather than simply providing energy.

6) Because comfort is improved when system users pay attention to their habits relative to the time of day and changes in weather, DC microgrids encourage conscientious use of resources among end users.
7) DC microgrids break the mindless fascination with newness, and employ of mix of very old and very new technologies.
8) ***DC microgrids are the only power supply approach we have seen that is economically viable for supporting modern comforts in communities of very modest means around the world.***

DC microgrids could be constructed in rural or semi-urban environments. Though the services provided are similar, cultural acceptance in the early phases of the expansion of this model will be greater in areas not already reliably supplied with reliable AC grid power. Living Energy Farm is seeking partnership opportunities for building DC microgrids in low income villages.

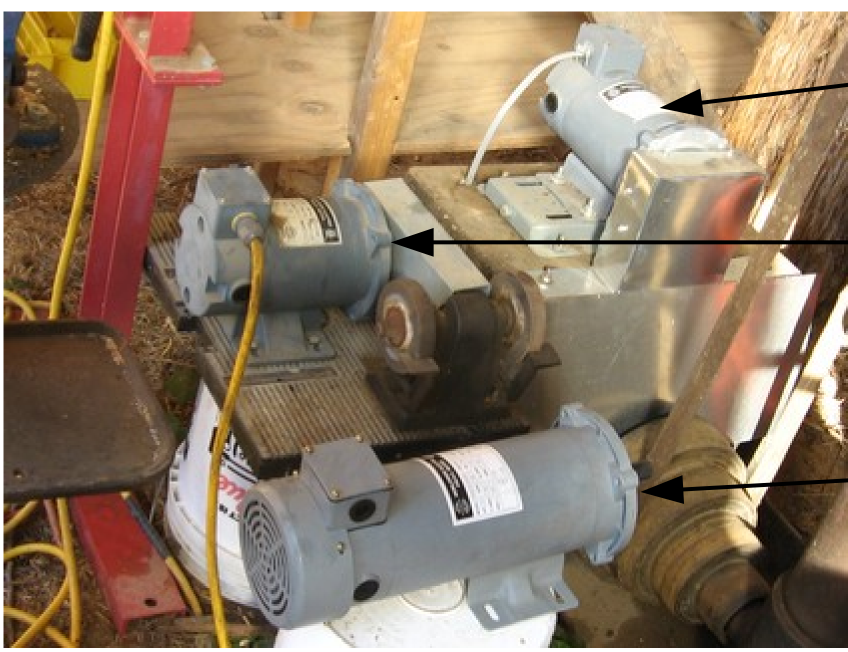
livingenergyfarm.org
livingenergyfarm at gmail

An Integrated Village DC Microgrid
Piece by Piece

1) Daylight Drive, High Voltage Systems

This is our main high-voltage power rack. It is 6 - 30 V panels in series, 6X30 = 180V DC. That is an industrial voltage, which means motors are cheap and easy to find. With this rack, anytime during the day, we run many motors with no inverters or other electronics. Sun comes up, motors run. Sun goes down, motors quit. It's that simple. And it is much, much cheaper than other electrical power supply systems.

The power from this rack runs directly (with no inverters, voltage controllers, nothing but switches) to the following equipment:
1) our main well, supplies drinking and irrigation water
2) heating blower for main house
3) heating blower for kitchen, which is separate from the house, and also functions as an industrial food dryer
4) seed drying blower
5) firewood saw
6) drill press
7) compressor
8) fine cut bench grinder
9) coarse cut bench grinder
10) band saw
11) fan for winnowing seeds and summer cooling.
12) and other shop tools, like a lathe or milling machine, as we get them set up.



1/2 HP 180 V DC motor, runs drill press

1/3 HP 180 V DC motor, runs bench grinder

1.5 HP 180 V DC motor. ALL of these motors can run at once from a 1.5 HP power source.

An Integrated Village DC Microgrid
Piece by Piece

2) Lighting

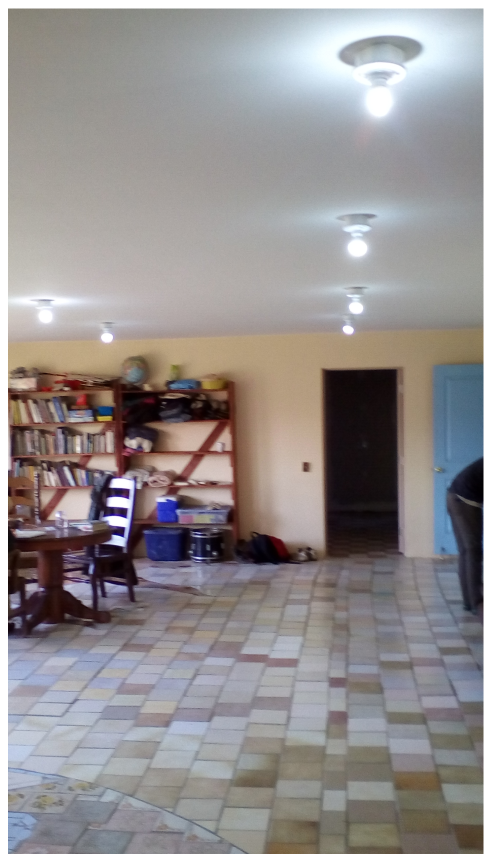
The DC electricity from this ***one*** PV panel goes to

this charge controller, to

this set of very, very durable nickel-iron batteries, then to

power tools. We take cordless tools, pull out the batteries, and run a cord back to the nickel-iron batteries. 18 volt tools run fine at 12 or 24 volt, the miracle of DC.

keeping the lights on. We used lead-acid batteries for a while when we were starting out. The nickel-irons are much, much better. We have no trouble keeping the lights on, even in cloudy spells in the winter.

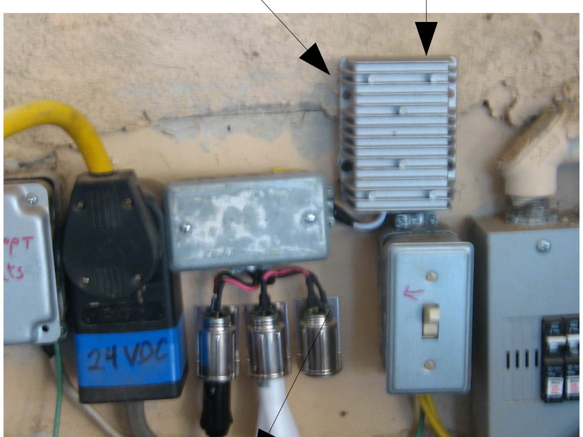


An Integrated Village DC Microgrid Piece by Piece

3) Daylight Charging, Phones, Laptops, Etc.

The DC electricity from a second PV panel goes to

This DC to DC converter/ regulator (which cost $30). Then we charge anything we want on the cigarette lighter plugs, then



we surf. The charging system, like the rest of our DC equipment, floats. It charges quickly in sunny weather and slowly in cloudy weather. Either way, it takes care of itself.

4) Refrigeration

One PV panel like this will also power a fridge from Sundanzer. This is their ddr165, which is made to run “direct drive,” which we call daylight drive.

The bigger Sundanzers are made to run with battery backup. This one is a bit smaller, but can run straight off the PV panel, no inverters, no batteries, just daylight drive, like we like it!

An Integrated Village DC Microgrid
Piece by Piece

5) Water Supply

These are the control switches at out high-voltage PV rack. The timer on the right gets turned on once or twice a day to turn on the pump and pressurize the system.

Several pump companies make high voltage DC pumps (Sun Pumps, Grundfos, Lorentz). Most submersible pumps are centrifugal, which means they pump more volume at less pressure. The pump companies, recognizing the floating power supply of daylight drive systems, are now making “helical rotor” pumps that pump high pressure with very low power input. The pump above is a helical rotor pump. It is a very narrow pump so it can fit in hand-dug, narrow pipe wells in non-industrialized countries. With a helical rotor, you don’t really need a timer like we have at LEF. But we prefer to interact with our water supply so people do not take it for granted.

Most rural homes have a 20 - 30 gallon water storage tank, and rely on a pump that can run anytime of the day or night to supply water. Normal off-grid design relies on many thousands of dollars of electrical hardware to run conventional AC pumps at night. At LEF, we have 3 tanks like the one above, 120 gallons each. These tanks are not free, but overall system costs are much lower than conventional design. One can also put in a more modest tank(s), and add storage later.

6) Water Heating

The solar hot water heating system at LEF consists of 8 flat plate solar collectors (3 at left). These systems are not cheap. They represent a relocation of capital investment from a power plant (as with grid power) to the home. The per-capita cost is not bad (less than $1000). The overall efficacy is great. We have a backup wood fired water heater, but we use it only a few times a year. We take hot showers any time we want, 365 days a year, with no fossil fuel. Such hot water systems would be entirely unnecessary in warm climates. In such places, a cheaper batch collector (a tank in a box with glass over it, pointed to face the sun) would suffice, if hot water were desired.

This 20 watt PV panel supplies power to this little daylight drive pump, called an El Sid. The SID pumps glycol from the panels

through a heat exchanger in this tank, which heats our water. We have enough hot water to last for at least a few days in cloudy weather.

An Integrated Village DC microgrid, How Does it Work?

This is the DC electrical system at Living Energy Farm. We will show how it works, piece by piece.

High voltage (180V) DC switch and plug for running daylight drive equipment that runs when the sun is out.

Plug for running recorded cordless tools (see next page).

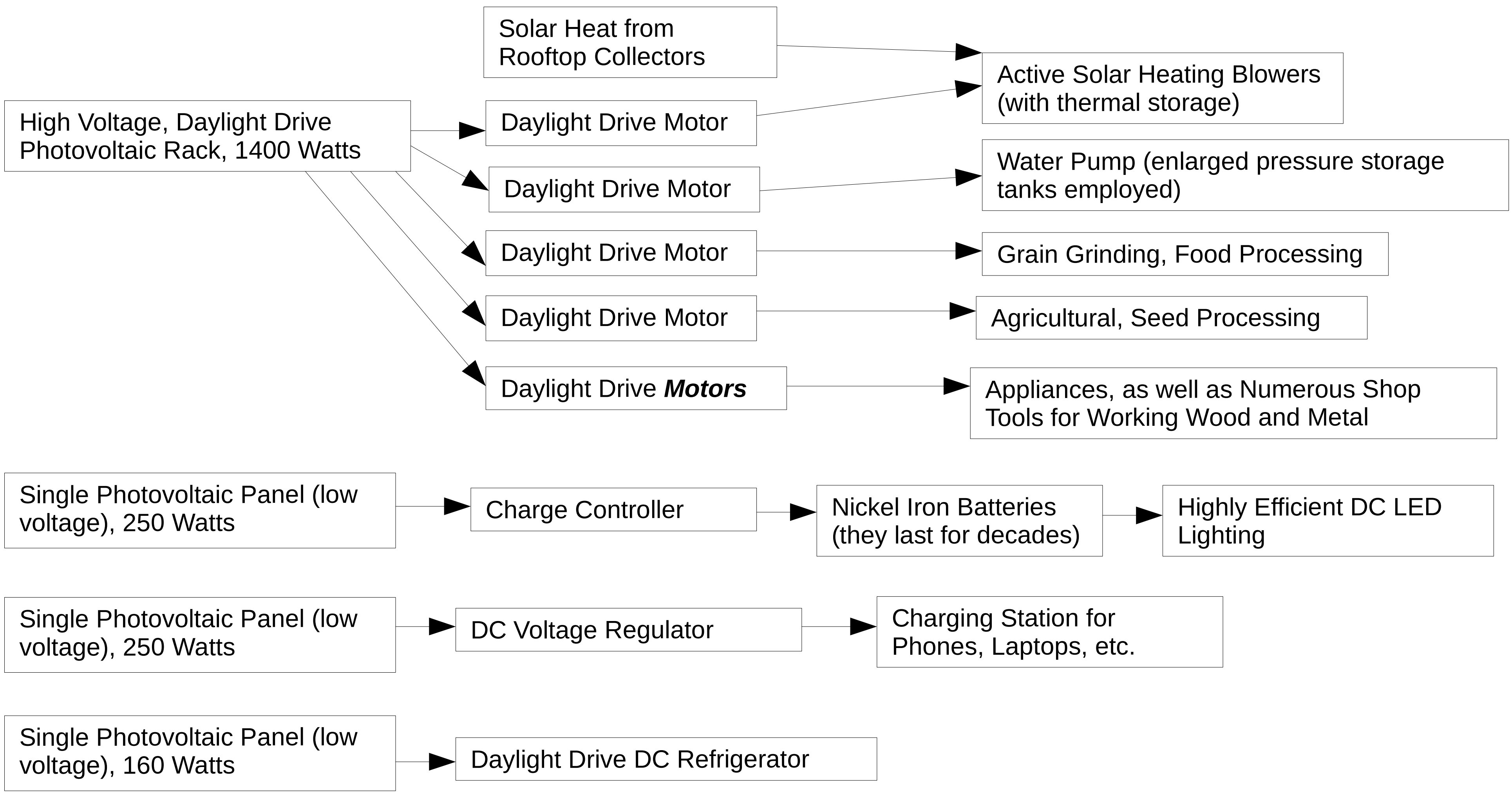
12 Volt cigarette lighter plugs for laptops, smart phones, and anything that can charge off of a USB plug.

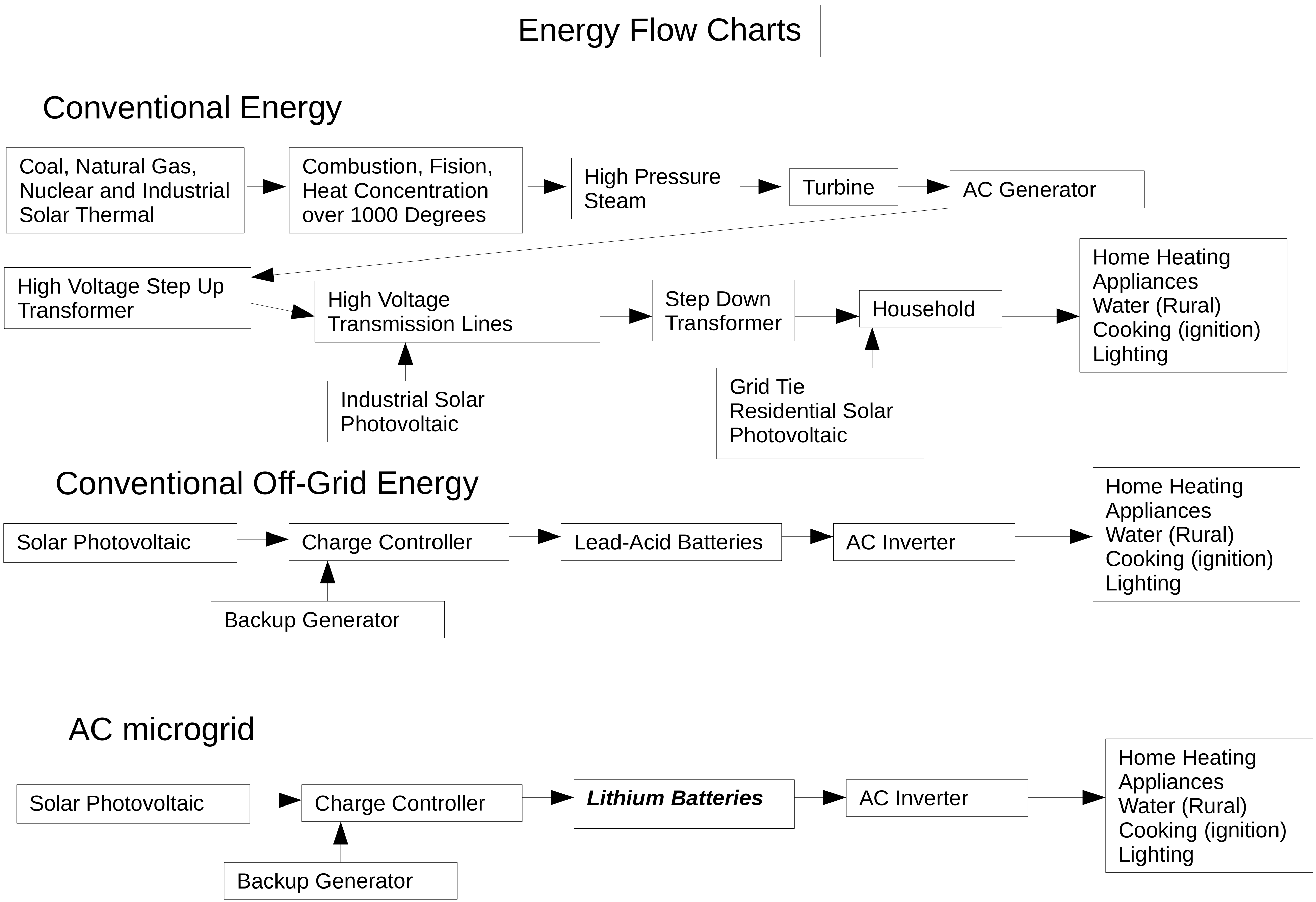
DC to DC voltage converter/ regulator feeds power to the cigarette lighter plugs

Circuit breakers for lights.

DC charge controller for nickel-iron batteries.

DC microgrid Flow Chart, As Developed at Living Energy Farm





Energy Flow Charts
Conventional Energy
Coal, Natural Gas, Nuclear and Industrial Solar Thermal
Combustion, Fision, Heat Concentration over 1000 Degrees
High Pressure Steam
Turbine
AC Generator
High Voltage Step Up Transformer
High Voltage Transmission Lines
Industrial Solar Photovoltaic
Step Down Transformer
Household
Grid Tie Residential Solar Photovoltaic
Home Heating
Appliances
Water (Rural)
Cooking (ignition)
Lighting
Conventional Off-Grid Energy
Solar Photovoltaic
Charge Controller
Backup Generator
Lead-Acid Batteries
AC Inverter
Home Heating
Appliances
Water (Rural)
Cooking (ignition)
Lighting
AC microgrid
Solar Photovoltaic
Charge Controller
Backup Generator
Lithium Batteries
AC Inverter
Home Heating
Appliances
Water (Rural)
Cooking (ignition)
Lighting

Comparison of Energy Sources for Stationary (Non-Transportation) Energy for Application in Residential and Small Scale Commercial Settings

Note, AC microgrid refers to new technologies using solar-powered microgrids as employed by Tesla and other companies.

Conventional AC Grid

1) General Design: Provide AC power from very large power plants to cover ALL demands.
2) Energy Flow: Linear
3) System Failure: ALL services fail instantly when there is any break in the linear production and distribution network.
4) Supports What Kind of Design? Because enormous capital is invested in remote power generation that consumers pay for only in small installments, centralized AC power systems support inefficient (capital minimal) design in housing and appliances. Badly insulated houses still stay warm in winter. Cheap, inefficient appliances work fine.
5) Historic Roots: Centralized AC power systems are a product of the early industrial use of steam boilers. The per-unit (KW or HP) output cost of such boilers declines dramatically at larger scales, and small

Conventional Off-Grid

1) General Design: Solar photovoltaic power charges lead-acid batteries, an AC inverter supplies ALL power demands.
2) Energy Flow: Linear
3) System Failure: ALL services fail instantly when there is any break in the linear storage and distribution network. System shuts down easily and often when batteries weaken.
4) Supports What Kind of Design? Because capital cost is borne by the user, a conservationist design is supported. But because of the mimicry of centralized AC systems, high-powered but short-lived lead acid batteries are employed, resulting in unreliable and expensive long-term operating costs that very few users choose to maintian.
5) Historic Roots: Developed in recent decades as an alternative to centralized AC systems, but because of pre-existing expectations of the power and performance of AC equipment, these systems are designed to mimic AC power.

AC microgrid

1) General Design: Solar photovoltaic power charges lithium batteries, an AC inverter supplies ALL power demands.
2) Energy Flow: Linear
3) System Failure: ALL services fail instantly when there is any break in linear storage and distribution network.
4) Supports What Kind of Design? Even though the energy source is solar, the capital costs are not borne by user. Because of this and because this technology is being added to existing inefficient AC networks, there is no motivation to conserve.
5) Historic Roots: Recent technological development. The long-term viability of lithium batteries is *probably* better than the lead-acid batteries used in conventional off-grid design. However, even the lithium batteries fail in ten years. Having to replace major system components every ten years is likely to prove

DC Micro Grid

1) General Design: Multiple DC power sources, high and low voltage, flowing down multiple paths to multiple demands.
2) Energy Flow: *Multi-linear*
3) System Failure: *There is NO general failure of services because of multiple sources feeding multiple demands. Services may weaken, giving users time to correct the problem.*
4) Supports What Kind of Design? Capital costs are borne by users. Also, operation of system is contingent on slowly weakening storage devices. A very strong conservationist design is supported.
5) Historic Roots: A very recent innovation employing both very old and very new technologies. This is the ONLY approach that breaks the cultural model that presumes AC power will be universally available. As such, it is both extremely efficient, and may face a hurdle of acceptance, particularly in wealthier areas.

Comparison of Energy Sources for Stationary (Non-Transportation) for Application in Residential and Small Scale Commercial Settings (continued)

Note, AC microgrid refers to new technologies using solar-powered microgrids as employed by Tesla and other companies.

Conventional AC Grid

private boilers were NOT an option for workers, homeowners, or shopkeepers in the early industrial revolution.

6) Overall Environmental Footprint: Extremely high, with most of the cost “externatlized” to future generations.

7) Cost: As long as externalities are ignored, grid power is very cheap in areas with access to abundant coal, gas, and/ or nuclear resources. Islands or other areas without coal or gas have much higher costs. Unfortunately, because of the cultural presumption that grid power is best, remote locales are often standardized to centralized grids even though other power options may be much cheaper. Putting boilers on sunny islands is foolish, but that is the dominant model.

Conventional Off-Grid

Because of the pre-existing expectations of on-demand power use, lead-acid batteries are employed, which destroys the long-term viability of this approach.

6) Overall Environmental Footprint: Much lower than grid power in most cases, because the design motivates efficiency. Photovoltaic panels have some environmental cost, and lead-acid batteries are very toxic. There are no industrial lead smelters in the U.S. because of the toxicity. Mimicry of grid power encourages consumerism, which often overloads power supply.

7) Cost: Long-term operational cost is very high. Most people who try conventional off-grid systems abandon them when they realize that their lead-acid battery sets degrade at a cost of $1000/ year for residential systems.

AC microgrid

financially disastrous in the long term. A more critical weakness is that, in trying to mimic centralized AC systems, all of the weaknesses of that approach represent a severe burden, particularly the support (based on the locus of capital investment) of extremely inefficient design.

6) Overall Environmental Footprint: Probably lower than grid systems, but the mimicry of grid power encourages consumerism, which may fatigue power supply. Long term viability of large scale lithium battery installations is uncertain.

7 Cost: We do not know enough about this new technology to assess long-term costs. Lithium batteries may, or may not, have a favorable long-term cost compared to other battery systems. The mimicry of AC grid systems greatly increases overall costs, complexity, and impact.

DC Micro Grid

6) Overall Environmental Footprint: Much lower than any other option, largely because of the design motivation to conserve. Some of the up-front capital cost is shifted from the power station (as with grid power) to the household. This makes both the financial, as well as the environmental, price of different choices more immediately evident.

7) Cost: Long-term costs are much, much cheaper than any other option. Costs are much cheaper in warmer climates (household heating and water heating systems increase costs, and are not needed in tropical climates). DC microgrids, like other renewable energy systems, work best at a village level, not for a single household. At the village level, with the integration of systems so one energy source can supply many needs, per-capita costs are low. A boiler economy is centralized, a solar economy is modular.

The Living Energy Approach

The Living Energy approach is to use solar photovoltaic (PV) power live, as much as possible, when the sun is out. This is our main high voltage (1400 watt, 180V DC) PV rack. LEF is not dependent on coal, nuclear or gas power. Normal PV grid-tie systems are 2000 to 5000 watts per person, and leave users ***fully dependent*** on nuclear, coal and fracked natural gas to supply power when it is not sunny.

Modern AC microgrids much more expensive than the Living Energy model because they are based on the AC grid model. They also employ costly lithium batteries. In theory, these lithium batteries will last 10 years. How many cell phone and laptop batteries do you use in 10 years? Those are lithium batteries. Is it wise to base ALL of our vital power needs on a single, linear power supply that is critically dependent on energy sources that fail so easily?

Electricity storage is expensive. The Living Energy approach is to store energy in forms other than electricity. The blower above runs live, with the sun. It pulls a lot of hot air off solar collectors on the roof, and blows the heat under the floor. Heat is stored under the floor so we don't have to run a heating system at night. To heat a house to 70 degrees in winter, you only need slightly more than 70 degrees blowing under the floor. The heat keeps the house warm for days. The conventional AC grid burns combustibles at a couple thousand degrees to make super-heated high-pressure steam, which generates mechanical power, which is then converted to electrical power (at less than 35% efficiency), that is then shipped at a 10% loss down high voltage lines, all to make 70 degrees at the end of the line. Such power conversions are extremely inefficient.

The Living Energy Approach

The power supply coming from PV panels can fluctuate wildly during the day. DC power systems float as the power supply floats. We use numerous "daylight drive" motors at LEF connected directly to the PV panels. We can run motors on cloudy days. The miraculous part is that we can also run motors that radically exceed the power supply. At LEF, our main PV rack is 1400 watts, which is about 1.5 horsepower (HP). We can run 2 or 3 HP worth of motors with only 1.5 HP worth of power supply. The motors simply speed up and slow down as power supply fluctuates. Our well pump is 1.5 HP and runs fine even with 3 HP worth of motors running from a 1.5 HP PV source. (As per the photo above.)

Conventional off-grid design would hope to reduce ecological impact, but it has two weaknesses. Firstly, lead acid batteries are used, which fail in a few years. Secondly, inverter supported AC systems have to have MORE supply than demand. As soon as the voltage drops, the whole system shuts down, literally leaving the users in the dark. The expense of battery replacement and system unreliability are the reasons that not many people live off grid.

Firewood is our backup fuel, our energy source when solar power runs out. This is our our daylight drive firewood saw. It will cut an 6 inch log as fast as a chainsaw. Daylight drive high voltage DC is powerful.

Daylight drive seed winnowing fan. (Works for keeping kids cool in the summer too.)

The Living Energy Approach

Direct drive compressor. With blowers, we can turn them on and forget them. The motors speed up and slow down as the power supply fluctuates. With the grinder and the compressor, the motors are under continuous heavy load. We cannot run them if the power supply falls too far.

Daylight drive grain grinder. We live on a plant based diet as that is most sustainable. We grind all of our own grains, and we grow quite a bit of it ourselves.

Seed drying blower. This one runs for months on end without our touching it.

We have a shop with woodworking and metal working machines, all daylight drive. This is an industrial drill press.

More Daylight Drive Equipment

Daylight drive fine grinder for sharpening tools.

We love our 180 volt daylight drive because we can run powerful motors all over the community connected by small wires. But for remote use, low voltage daylight drive works too. This is a 24 volt daylight drive irrigation pump.

Daylight drive blower that heats the kitchen. We built a closet around the blower and put a diversion in the duct so we could blow hot air through the closet, which then functions as an industrial scale food drier.

Mason jars full of dried food. For some seeds crops, like corn, you can plant it or eat it, but not both. For other seeds crops like peppers, we can save the seed AND dry the flesh of the peppers for later eating. These are jars full of many kinds of dried fruits and vegetables. The heating system in the kitchen doubles as a large food dryer.

The Living Energy Approach for Home Lighting

Homemade NiFe battery at LEF. Low power density is fine for residential use.

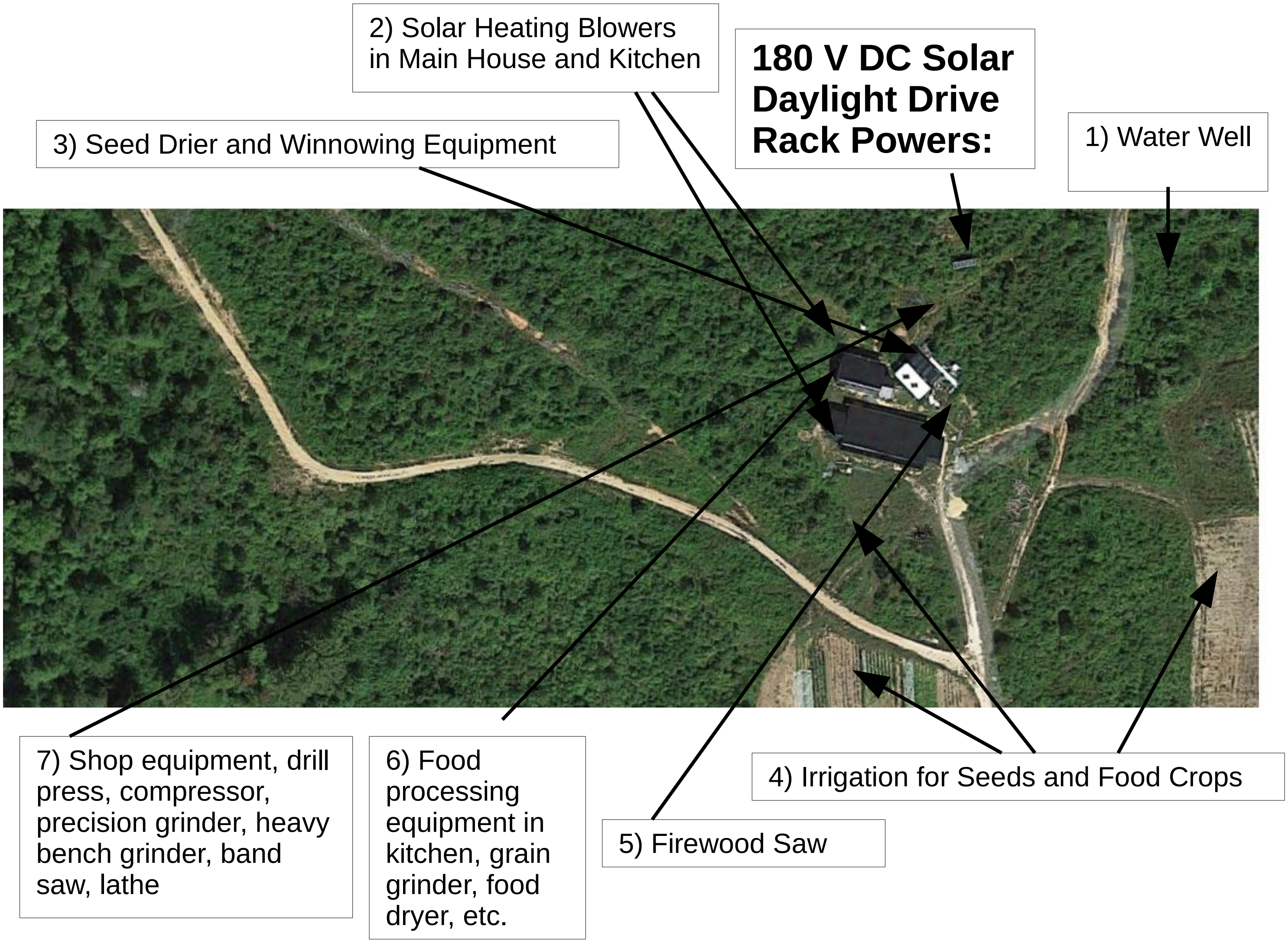
Living Energy Farm is a community of people. To keep the lights on in ALL of our buildings YEAR ROUND requires the output of exactly ONE 250 watt PV panel. That is not a lot of power. Why is our lighting system so very efficient? Several reason. We store electricity ONLY to run lights at night. We have various means of storing energy OTHER than electricity. We store heat in the rock and dirt under the floor of the house so we don't have to try to run a heating system at night. We run heavy DC motors during the day with our daylight drive systems, so we don't have to store electricity to run appliances or other motors at night. For lighting, we use DC LED light bulbs wired straight to the batteries, no inverters, no fancy electronics. The DC LEDs are so efficient we can light a bedroom with only 6 watts! The final reason our lighting system is so efficient is that we use Nickel Iron (NiFe) batteries. In our time, there tends to be a disdain for old technologies and an assumption that newer is always better. At LEF, we combine new and old technologies to meet our goals. NiFe batteries were developed by Thomas Edison. They were in common use in industry 60 years ago.

To our knowledge, NiFes are the only battery technology ever developed that suffers no degradation on each charge cycle. With every other battery, each time you charge and discharge it, the battery is degraded. Lead-acid batteries are standard, but they are a horrible technology. They are fragile, and short lived. The picture here is a 100 year old NiFe battery lighting up a light. No joke!

If NiFes are so good, why has no one heard of them? Because they are bulky. ALL of the battery research for decades has focused on small, power-dense, portable, fast-charging batteries. None of that matters for residential use. Durability has been ignored. This is the modern, Chinese made NiFe set we have at LEF. It's about 3 feet wide, and has the same capacity rating as a lead-acid car battery, but the rating is wrong. In practical use, NiFes radically outperform lead-acid batteries. `

Living Energy Farm DC Microgrid Energy System

One power source supplies *many* needs, all close together.



How Are We Going To Live Without Fossil Fuel?

Step 1, Put Things in Their Proper Place

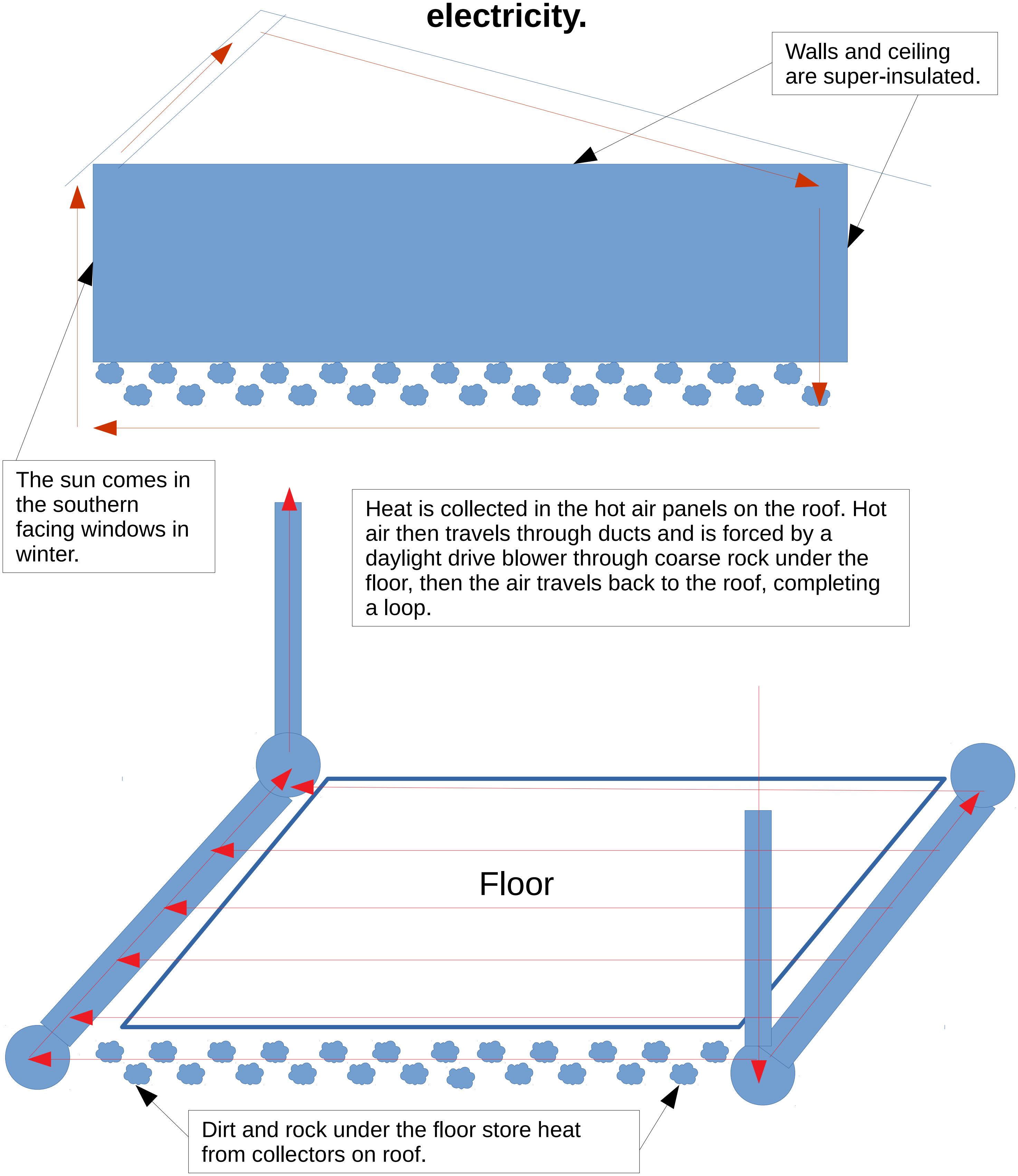
It would not work for our major environmental groups to keep themselves afloat financially while challenging the consumeristic American lifestyle. Instead of attacking lifestyle choices, we tend to focus on "renewable" energy production. This has led to some gross misunderstandings about what is really involved with moving beyond fossil fuel.

If we are to live without fossil fuel, the MOST IMPORTANT issue by far is design, where buildings and workplaces are situated and how they are used. Work and living spaces need to be arranged so they can share support systems. (We call this integrated design.) We have to maximize shared use. This is the single most powerful renewable energy "technology" available to us. Sharing the use of integrated renewable energy systems allows us to divide the these systems among many users, while these same people reap the benefits.

Integration and shared use are what make renewable energy work. This is based on the laws of physics, not personal preferences. Not all renewable energy sources are the same, but generally speaking, renewable energy systems are not effective or efficient if they are too large or too small. We cannot build personal efficient houses, solar hot water systems, or solar electric systems for each of the 7.5 billion people on our planet, or for each individual family. But with shared use and integration of systems at a village level, we can easily live within a renewable energy budget.

How to live without fossil fuel, step 1, put things in their proper place, step 2, insulate and conserve, and step 3, build integrated village renewable energy systems. A REVERSAL OF THESE STEPS DOES NOT WORK. And, sadly, is also the norm....

Living Energy Farm Solar Design
Stores energy as heat, eliminating need for stored electricity.



Community House at LEF

Solar hot water, closed loop to storage tanks, daylight drive.

Solar hot air from roofs pumped under the floors by daylight drive DC blowers.

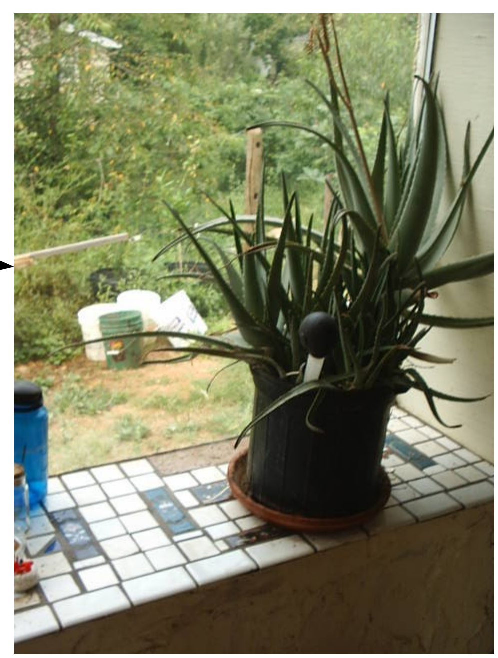
Doors and windows on opposing walls, facilitates ventilation.

Passive solar, windows on south side.

Stud frame house with strawbales leaned against the walls, super-insulation at the same price as conventional construction, well suited to community building parties.

LEF's main house stays warm through an entire winter with almost no firewood.

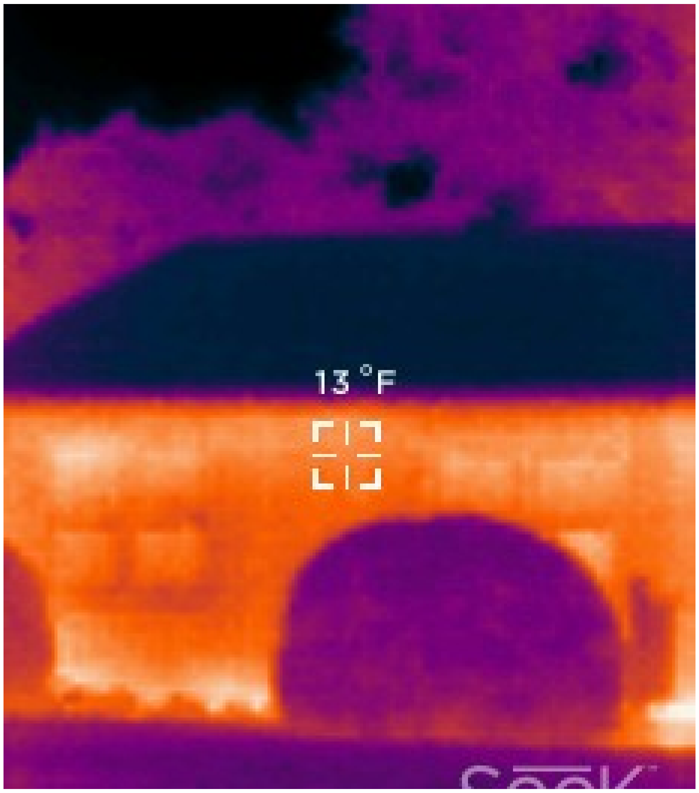
Super-insulated walls cost no more than ordinary walls, they are just thick! This photo is from a retro-fit where bales were wrapped around an old house. This is not normal because it mimics the historical building style of the poor, whereas construction techniques in the U.S. are dominated by mimicry of the wealthy.



Built with bamboo and crumpled newspaper. Super-insulation is easy and cheap!

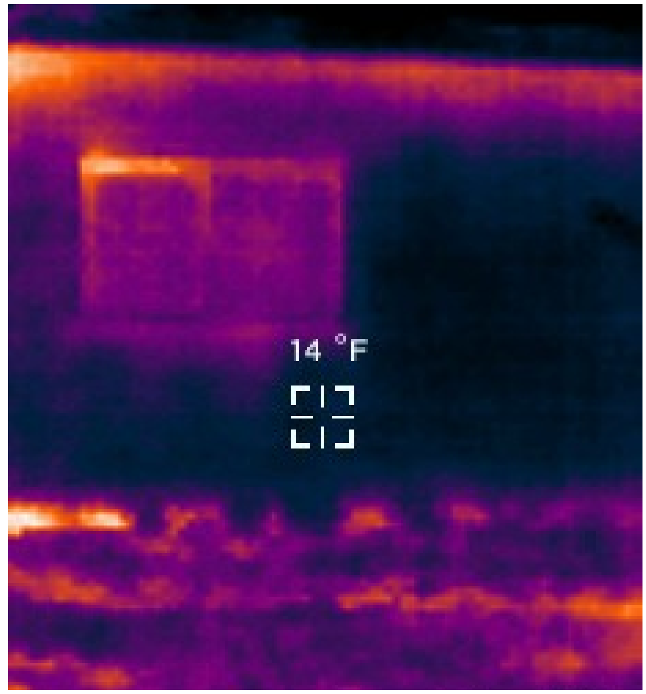
Home Heating and Cooling

Centralized AC Grid



In cold climates, home heating is the number one demand on residential energy systems. This is an infrared picture of a “normal” house on a winter night. The brighter areas show warmer temperatures. The house looks like it is on fire. The whole wall is much warmer than the outdoor temperature, which represent massive energy leakage. Because the heavy capital costs of grid power are centralized and consumers only pay in small increments, inefficient design is supported.

The Living Energy Approach



This is an infrared picture of our main house at LEF on the same night in winter. Notice the wall of the house is actually colder than the ground in front of the house. The strawbale walls of this house have 3 times the insulation value of a normal house **and cost no more to build than “normal” walls.** That being true, then why are poorly insulated houses the norm? Because **the building trade is guided by mimicry of the palatial houses of the wealthy, not what works functionally.**