# The Direct Drive DC Microgrid: An Energy Future the Whole World Can Afford

*By Debbie Piesen*

*Living Energy Farm members and volunteers, in the summer of 2024.*

*Cooking green beans with biogas! We use burners made especially for biogas, as they work better than modified conventional gas stoves in our experience. Home Biogas is a good source for burners.*

*A winnowing fan modified to run direct drive.*

In 2010, a group of eight people came together to start Living Energy Farm (LEF) in Louisa, Virginia. Our mission was to demonstrate that a fulfilling life is possible without the use of any fossil fuel. We wanted our demonstration village to be accessible to all persons regardless of income. Each member of our group was a current or former member of Twin Oaks Community or Acorn Community (both are income-sharing communes also in Louisa). We all knew by then that community living is more sustainable than the mainstream. For anyone living in a single family home, it's an uphill battle to compost, afford solar equipment, avoid driving, or grow your own food. Simply by sharing—whether it's energy systems, housing, meals, tools, childcare, etc.—community makes it easier to live sustainably.

And yet, even in intentional communities, it is not easy or cheap to transition to 100 percent renewables. Communities that try to go off-grid often end up connecting back to the grid over time. Either their system doesn't work well, or they realize they're spending more replacing batteries than they would be spending on utilities. At LEF we wanted to avoid the high cost and ecological footprint of large battery sets. We assumed this would mean mostly doing without modern conveniences. So we called ourselves "neo-Amish" (Amish without the patriarchy). We stockpiled beeswax for candles, bought hand tools to replace our power tools, and researched rocket stoves for cooking.

Communities often turn out pretty different from the founders' original vision. That was certainly true for us, and mostly for the better. Through years of tinkering and technology development work, we are now living off the grid in more comfort than we ever thought possible. We can take a hot shower whenever we want, surf the internet, heat our home, run a machine shop, dry our crops, cook our meals, and more—with no grid power, no generator, and very little firewood—all with our community's direct drive DC Microgrid.

We do make some adjustments. We bake bread and do laundry when the sun shines, and use efficient laptops instead of desktop computers. I'll take a navy shower if it's been cloudy for several days. But it's really not so hard. What makes our microgrid work is good design, prioritizing conservation, and—mostly importantly—living in community.

## What the World Can Afford

Most climate change mitigation strategies call for mass electrification of energy demands, to be powered by solar and wind, and backed up with battery storage. Activists and observers are starting to become alarmed by the economic, environmental, and human rights implications of a build-out of PV, wind, and battery storage on scale to meet the American appetite for energy. There's good reason for this alarm. To meet residential energy demands with renewables in our bioregion—Mid-Atlantic US, which has four hours of sun per day on average[1], and little useful wind—requires approximately 12kWh of battery storage[2] and 3kW of photovoltaic (PV) panels[3] per person. We're nowhere close to installing this much PV and battery capacity, and already lithium mines and other extraction projects required for "green growth" are creating environmental devastation and human rights violations around the globe.[4]

By comparison, direct drive DC Microgrid at Living Energy Farm consists of 250 watts (.25kW) of PV panels and 200 watt hours (.2kWh) of battery storage per person. Our microgrid design requires eight percent as many PV panels and **two percent as much battery capacity** as is needed to provide residential energy services with conventional solar and storage systems that supply AC (alternating current).[5]

So how, at Living Energy Farm, do we manage to power an almost-middle-class, and certainly modern lifestyle, with such a small resource footprint? At LEF we use batteries only for very small loads (lights, fans, and electronics).[6] The majority of the energy in our microgrid is stored in forms other than electricity, and is delivered by one of three systems: **solar thermal**, **direct drive**, or **biogas**. I'll explain these systems one at a time.

## Solar Thermal

In our climate, the three biggest residential energy end-uses are heating,[7] cooling, and

*Our entire metalworking shop is powered by direct drive, including the milling machine that Nika is running in this photo. Alexis teaches a shop class to the kids from LEF and neighboring communities once per week.*

*A solar direct refrigerator, installed by Living Energy Lights' team at Solidarity Yaad farm in Jamaica. The fridge is a great example of non-electric (thermal mass) energy storage.*

*Each day Otto feeds the biogas digester about a half bucket of biomass—grass clippings, kitchen scraps, seed-processing chaff, etc.—causing effluent overflow into a storage tank. Effluent is then pumped onto our orchards and gardens, completing the nutrient cycle.*

*This is the shed that houses our biodigester. The digester itself is a plastic tank surrounded by strawbales and cellulose insulation. The thermal collectors on the roof supply heat to the digester. The blue bag on the right is our biogas storage.*

Photos courtesy of Living Energy Farm


*We build insulated solar electric cookers (ISECs) in our shop at LEF. In the photo above, Debbie (the author) teaches about ISEC construction as part of our annual DC solar training program.*

*This buzz saw, made to run off of a tractor PTO at 20HP or more, cuts firewood via direct drive with just 1.4kW of power (about 2HP) using a permanent magnet DC motor.*

*Another example of non-electric storage: a pressure tank supplies water pressure at night, when our pump doesn't run.*

water heating. For summer cooling at Living Energy Farm, we use fans, shade trees, and cross-ventilation. For space and water heating, we use solar thermal systems that capture and store solar energy as heat, not electricity. These systems are durable and reliable, but also take significant resources and skilled labor to design and install. Cooperative housing is what makes them both effective and affordable. In multifamily homes there is less perimeter per unit of thermal mass, which allows for more effective heat storage and less heat loss. Also, economies of scale and shared systems make a dramatic difference in the cost per capita of solar thermal.

That's why step one is cooperative use. Step two is insulation. Solar energy, for all its virtues, is pretty wimpy compared to other sources of heat—especially in winter, when we need it the most. So there's really no way to stay warm with solar without very high insulation standards. Our preferred method is to build a conventional stick frame, and stack strawbales inside the frame. But more important than the type of insulation is the quantity. You'll need thick walls, good quality windows and doors, and adequate ceiling insulation.

Step three is to build an active solar heating system, in which thermal collectors capture solar heat to be moved into storage. (In this context, the word "active" differentiates these systems from "passive" solar heating, which does not pump air or fluid into storage.) Solar thermal collectors can heat fluid—typically water or antifreeze—or air. They are at least three times more efficient than solar electric panels at turning solar energy into heat.[8]

Direct drive pumps and blowers move solar-heated fluid or air into storage. Heat is stored not in a battery but in thermal mass, which may be water in a tank, gravel and dirt under the floor, or the floor itself. Thermal mass is cheap, durable, and much better than batteries at storing heat.

Solar thermal is nothing new; it's been around for decades. We helped many of our friends install systems back in the '90s. But interest in thermal systems has declined since the '00s, even as grid-tie PV becomes more popular. Most solar installers no longer install solar thermal, citing the faster payback of PV systems.[9] While it's true that incentives have brought down the cost of PV, it's also true that building a solar thermal system takes more skill than building a PV system. (Wires bend more easily than pipes.) Most solar installers simply don't know how to design or build solar thermal systems, so they don't recommend them to their customers.

These trends are unfortunate, because we need solar thermal systems more than ever. A solar thermal system is the only heat source that is both environmentally benign and resilient. Rural communities often burn firewood for heat, but this reduces air quality and has a high carbon footprint.[10] Heat pumps are touted as the environmental alternative, but they create a dangerous reliance on the grid for heat as winter storms become worse, and outages more common. It's pure fantasy to imagine that we're going to keep all these heat pumps running with PV and industrial battery storage through a cloudy winter. In the real world, if you want a sustainable, resilient way to heat your home, what works is insulation and solar thermal. With these tools, we stay warm with no fossil fuels, no batteries, and very little firewood.

## Direct Drive

Direct drive (also known as daylight drive, or solar direct) means connecting DC (direct current) loads directly to one or more PV panels, with no battery storage or inverters. We did not invent direct drive at LEF—solar direct water pumping, for example, is used for irrigation around the world. But we are the only organization we know of that teaches people to build integrated direct drive circuits. This means that we power many DC loads directly from a single PV supply.

Direct drive does a LOT of work at LEF. The list of jobs includes: water pumping, cooking, refrigeration, food processing, metalworking (our shop includes a lathe, milling machine, band saw, grinders, air compressor, and more), seed processing, food dehydration, washing clothes, cutting firewood, heating our buildings (by blowing solar heated air under the floor), charging ebike batteries, and mowing the lawn. All this work is done by seven humble PV panels. And the list continues to grow. What makes direct drive so efficient, and cheap, is the fact that DC systems can be overloaded without any damage to the motors or the circuitry itself. This is NOT true for AC systems, which must be built with a reserve capacity to ensure motors receive full power. AC motors can only tolerate 10 percent voltage variation. DC motors, on the other hand, can handle 0-150 percent of their rated voltage without damage.

The voltage tolerance of DC vs. AC motors sounds like a minor technical detail. But the environmental and financial implications are huge. If you were to ask a typical solar installer to build a solar system to support our machine shop, for example, you would be looking at tens of thousands, if not hundreds of thousands of dollars in panels and batteries. Instead, we run our shop with $1,000 worth of PV panels—panels which, incidently, power a whole lot more than just the shop.

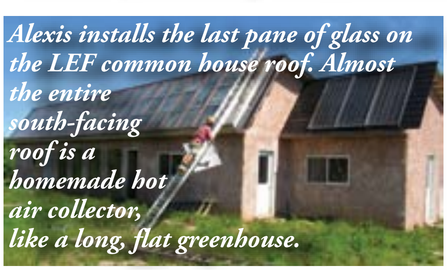
Sourcing equipment is an ongoing challenge.[11] Most AC appliances will not run on direct drive. At LEF, only two of our direct drive appliances were purchased as such: our pump and refrigerator. The rest we built or modified ourselves. One of the most important discoveries we made is powering belt driven equipment with permanent magnet DC motors running direct drive. These motors are commonly used in industry, therefore widely available, and very durable. They are the backbone of our farm, running all kinds of tools and equipment. We have also converted many appliances that have universal (AC or DC) motors, or nichrome heating elements, to run direct.

Non-electric energy storage is very important in a direct drive system. Our refrigerator, for example, runs only when the sun shines. It has extra-thick walls and a chest design, which ensure that the food stays cold overnight. For cooking with direct drive, we built our own Insulated Solar Electric Cookers (ISECs), designed in cooperation with a project out of Cal Poly University.[12] These cookers build heat gradually, allowing them to cook with very modest solar input. Another example of non-electric storage is pressure tanks. Our direct drive pump pushes water into tanks during the day. The water compresses air bladders inside the tanks, which maintain water pressure at night.

In our direct drive system, "load management" is fully manual. We install voltmeters, and watch how the voltage changes as we turn loads on and off. If it drops too low when a load is turned on, there's not enough sun to do what you're trying to do. You can wait for more sun, or turn off some other loads and try again. The system teaches you to use power when you have it, and conserve when needed.

We host volunteers at our farm, and new people often need time to adjust to direct drive, but almost everyone gets it in a week or two. It's a different relationship with energy, like growing your food instead of getting it from the store. It's a lot less work than

*Kathryn installs foam insulation along the inside of the LEF common house foundation in 2012. Sub-grade insulation is important in radiant floors built for thermal storage, to retain the heat pushed into the floor during the day.*



*Alexis installs the last pane of glass on the LEF common house roof. Almost the entire south-facing roof is a homemade hot air collector, like a long, flat greenhouse.*

*Strawbale construction is a great way to make use of low-skill community labor. This crew stacked 400 strawbales around Magnolia House in one day, in 2021.*

*Ricardo, Millo, and Marielisa all graduated from LEF's DC solar training program and are now installing systems throughout the Caribbean. This installation is in the mountains of Jamaica.*

*Marielisa wires a junction box for a 12VDC circuit at Magnolia Collective, as part of our 2023 training program.*

*Twelve electricians, activists, and farmers from Puerto Rico and Jamaica attend a training at LEF, summer 2023.*

growing food, though. And it's not a hard fit with the modern lifestyle, particularly in a community context, wherein someone—a retiree, remote worker, or childcare provider, for example—can probably stay home and make sure energy intensive work gets done when the sun shines. If you can grow a garden, you can use direct drive.

## Biogas

Natural gas, a fossil fuel that is mostly methane, was produced by ancient microorganisms digesting plants and animals over millions of years. At Living Energy Farm, we have the convenience of natural gas without fracking, pipelines, CNG infrastructure, and other undesirables, by making our own methane at home. It's called biogas.

Biogas is created in a tank known as a digester, or biodigester, which is like a liquid compost pile. Organic matter mixed with water is fed into the tank, and effluent comes out. Biogas accumulates at the top, and it can be burned just like natural gas. Like natural gas, biogas releases carbon dioxide when burned. But it's considered to be carbon neutral because carbon is sequestered in the process of growing the feedstock that goes into the digester. Still, methane itself is a greenhouse gas much more potent than carbon dioxide. While a biogas system is designed to burn gas, not release it, leaks can happen. In the early years of our community, we avoided investing in a biodigester, because of our concerns around methane leaks.

Over time, we came to the conclusion that biogas is an appropriate way to solve our cooking challenges. We decided years ago that we would not use propane. Solar cooking is great, except for when it's too early, too late, or too cloudy. For years, we tried to store solar heat at temperatures high enough for cooking. Solar heat storage isn't hard at lower temperatures—an insulated tank can maintain temperatures hot enough for a shower (110ºF) for several days. But cooking temperatures are 300ºF or higher. We can store heat at 300ºF for a few hours, but not overnight. And what about cloudy days? Firewood was our backup, and let me tell you from experience, starting a fire every morning for breakfast loses its charm pretty quickly. (And yes, it's worse for the climate than gas.[13])

We started investing seriously in biogas about five years ago. The biggest challenge of biogas production in our climate is keeping the digester warm. Methane production is optimal at 90-105ºF, and slows to a crawl below 80º. Community-scale biogas is more common in the tropics, for this reason. Home Biogas, an Israeli company that sells biodigester kits, instructs you to place their bag in the sun to keep it warm. That may work in Israel, but in Virginia this design will produce a decent amount of gas only a few months out of the year. We ran a Home Biogas system for a few years before deciding to build our own. Our current digester is a 2,000 gallon plastic tank. To keep it warm, we built the tank with an internal heat exchanger connected to flat plate solar thermal collectors, and wrapped the tank with two layers of straw bales and four feet of blown insulation over the top.

Biogas production is another great example of community living making renewable energy cost-effective. We don't recommend a biodigester for a single family. It requires significant up-front investment and ongoing care. You also need feedstock. We've had success feeding our digester grass clippings, kitchen scraps, biowaste from our farm, and human waste (we have a toilet connected directly to the tank). A single family would have a harder time coming up with enough feedstock.

It's also important to use biogas effectively. In the US, biogas is mostly burned for electricity or heat. This is very silly, because these energy needs can be met with solar, which is cheaper and doesn't require feedstock. The energy needs that our solar microgrid cannot supply are cooking and tractor fuel. For these needs, biogas is wonderful. And as long as we're careful, and cook with sunshine when we have it, we can store enough gas to keep us cooking through weeks of clouds.

## Where Do We Go from Here?

At Living Energy Farm we put a lot of time into teaching and supporting others to build DC Microgrids like ours. We host trainings once per year, and give tours once per month to groups ranging in size from eight to 30. Hundreds, more likely thousands, of people have seen our systems first-hand. Many of them tell us that our microgrid is the best off-grid setup they've ever seen. Dozens of people write us every year asking for advice on setting up their own DC Microgrid. And yet, very few of them actually build one. To date, we know of 15 direct drive DC Microgrids currently in use: three in Louisa, Virginia, two in Jamaica, and 10 in Puerto Rico.

As these numbers show, the direct drive movement is growing in the Caribbean. It's easier and cheaper to build DC systems in the tropics, where expensive solar thermal features are not needed. Also, both Puerto Rico and Jamaica have a privatized electrical utility that is corrupt, inept, and widely despised. So people are more motivated to go off-grid. Thanks to the educational efforts of our Caribbean partner organizations, word is spreading. It's not always an easy sell: well-off Caribbeans generally want conventional solar systems that make AC (alternating current), while many people who would be fine with DC systems are too poor to afford any solar hardware, even relatively cheap direct drive equipment. But we're making some progress.

Here in the US, things are moving more slowly. Like wealthy Caribbeans, Americans want the convenience of being able to use their AC appliances, and if they can afford big battery banks, most people will go that route. (We often tell these people to come to us when they're looking at their first battery replacement.) The convenience factor and the psychology of previous investment in AC appliances are both significant obstacles to adoption of DC systems. But for most environmentally-minded people, convenience or previous investment are not really the biggest barrier. Growing a garden isn't convenient either, and people still do it. The much bigger problem is that American environmentalists can't seem to cooperate enough to build and use shared housing and other community-scale sustainable infrastructure. This rules out cost-effective solar thermal and biogas systems. You just can't do it alone.

Intentional communities are the natural home for our technology; all three DC Microgrids currently in Louisa are, in fact, used by small communities. But the urgency of the climate crisis demands adaptation of the DC Microgrid beyond the intentional communities movement. To this end, we're seeking out partnerships with organizations in our region that work on affordable, cooperative housing and are interested in applying our energy model. We are in the beginning stages of a collaboration with Waterbottle Co-op, a worker-owned construction company in Baltimore that renovates row houses. Another potential project is in the works with Las Palmas, a nonprofit working on affordable housing access in our county. We look forward to seeing where these projects go in the coming years.

We believe that many people would choose to live with a DC Microgrid if the option were available to them. It's comfortable, joyous, and fulfilling. But it's not an option for most people, mainly because our culture values private homes. We can all be living in communities powered by renewable energy, if we choose to build them. Why not start today? ❧

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*Debbie Piesen (she/her) is one of the founders of Living Energy Farm and has managed the community's seed and food growing since 2011. These days, when she's not farming, Debbie can be found working on DC Microgrid installations, building solar cookers, and managing solar equipment distribution in the Caribbean. In her spare time, she enjoys music, Ultimate frisbee, and hanging out with her two kids, who are both named after persimmon varieties.*

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1. unboundsolar.com/solar-information/sun-hours-us-map.
2. www.solar.com/learn/how-many-batteries-do-i-need-for-solar. "A large solar system with 30 kWh of battery storage can meet, on average, 96% of critical loads including heating and cooling during a 3-day outage." Average American household size is 2.5 people. 30kWh/2.5 people = 12kWh/person. I ran this number past a few local solar installers I know, and they agreed that it was a reasonable average, if a little low.
3. 12kWh/4 hours per day = 3kW required to charge the batteries. Number should probably be higher to allow more buffer for clouds.
4. www.truthdig.com/articles/the-green-growth-delusion.
5. This number is likely too low, because the buffer for clouds in the Berkeley Lab battery analysis is very minimal.
6. We power these loads at 12VDC to avoid the need for an inverter, and use durable nickel iron batteries. Learn more at livingenergyfarm.org/12v-battery-systems-for-lights-and-electronics.
7. 2020 Residential Energy Consumption Survey, Table CE3.6, "Annual household site end-use expenditures in the United States—totals and averages" www.eia.gov/consumption/residential/data/2020/c&e/pdf/ce3.6.pdf. In the South Atlantic census division, average annual household expenditures for the top three energy end-uses are $431 for space heating, $367 for air conditioning, and $314 for water heating. We do not use air conditioning; instead we design buildings for ventilation, shade, and passive cooling, as well as using fans.
8. www.greenbuildingadvisor.com/article/solar-thermal-is-not-dead. This source claims a 12 percent efficiency for PV and 76 percent efficiency for flat plate collectors. This five-fold difference is probably too high, as other sources put PV at 15-20 percent efficient, while estimates range for flat plate and vacuum tube collectors from 50-80 percent, depending on conditions and quality of manufacturing. So we settle on 3X as more realistic number.
9. A typical argument for installing PV instead of solar thermal, although we disagree with their analysis. www.my-pv.com/en/news/photovoltaic-heat-vs-solar-thermal-cost-and-area-comparison. We have had a few friends ask us to take apart and haul away their old thermal systems, such is the lack of excitement around solar thermal these days. It's sad, although we've ended up with some good free equipment as a result.
10. Here's an article that summarizes environmental arguments against heating with firewood: www.theguardian.com/environment/2022/feb/25/pollutionwatch-wood-fires-bad-for-planet-more-evidence-shows. This website has a lot of information about the health impacts of wood smoke: www.dsawsp.org.
11. We started a nonprofit solar equipment company to distribute direct drive equipment: www.livingenergylights.com. On our website we maintain a list of other direct drive equipment suppliers: livingenergylights.com/direct-drive-appliances-available-through-other-suppliers.
12. livingenergyfarm.org/insulated-solar-electric-cooker and digitalcommons.calpoly.edu/mesp/494.
13. www.sciencedirect.com/science/article/pii/S0301421519304161?via%3Dihub. "Using a stove was found to be the least climate-friendly option to heat a house."