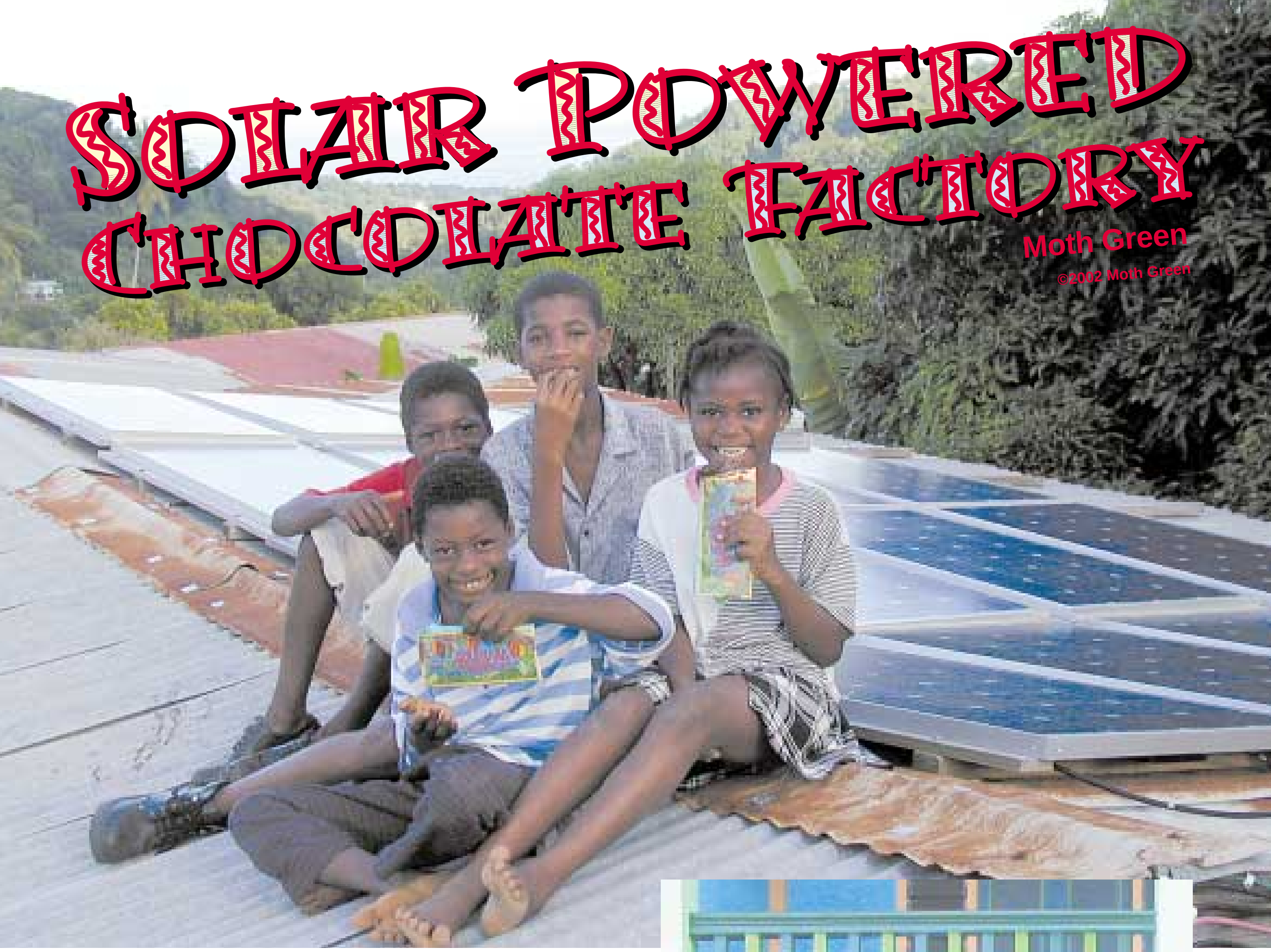
Solar Powered Chocolate Factory

Moth Green



Local kids get a taste of local chocolate and local energy.

While doing PV and intermediate technology volunteer work on the island of Grenada, I became fascinated with the cocoa tree. My favorite pastime became simple, kitchen-style processing of cocoa beans into luscious hot chocolate. After a while, I began to dream of creating a solar powered chocolate factory in the lush, cocoa-producing southern Caribbean.

Grenada Chocolate Co. founders Edmond Brown, Moth Green, and Doug Browne in front of their cottage factory.

Sixteen, 120 watt AstroPower modules provide power directly to DC-driven, chocolate making machines.

The price for cocoa beans paid to Grenadian producers is marginal compared to the price of fancy chocolate. So I began to fantasize about making dark chocolate with a cooperative that would actually benefit the cocoa farmers. Grenada's world famous cocoa would be used to create top quality, nonexploitive chocolate bars right in Grenada. Four years ago, together with two partners and a startup loan, I embarked on this chocolaty journey.

Fine chocolate making is a rather complex process involving several different machines. Fresh, pulpy cocoa beans are first harvested from the pods growing on cocoa trees. They are then fermented in a large wooden box for about seven days, and sun dried. The fermentation gives rise to all the chocolate flavors.

The dry cocoa beans are roasted, shelled, and ground together with sugar into a "liquidy" paste. Pure cocoa butter, pressed from other roasted cocoa beans, is added to this paste, and the mixture is further ground, tumbled, and slow-cooked for up to 48 hours. The resulting finished liquid chocolate is then tempered, molded, and cooled into chocolate bars.

The machines used in the process are the roaster, winnower, melangeur (chocolate grinder), cocoa butter press, refiner/conche, tempering kettle, and vibration table.

The melangeur is a refurbished antique chocolate grinding machine with two, 500 pound (227 kg), solid granite rollers. It has a retrofitted, 24 volt permanent magnet motor, and crushes the roasted cocoa beans.

The Research Stage

The first step in our chocolate odyssey was to convince a couple of big U.S. chocolate factories to allow us to see their process and machines. Later, we located a couple of textbooks on chocolate manufacturing. Quickly it became clear to us that small-scale machinery for quality chocolate making is no longer manufactured. The conversion of cocoa beans to bulk chocolate is only done at very large factories with very large machines these days.

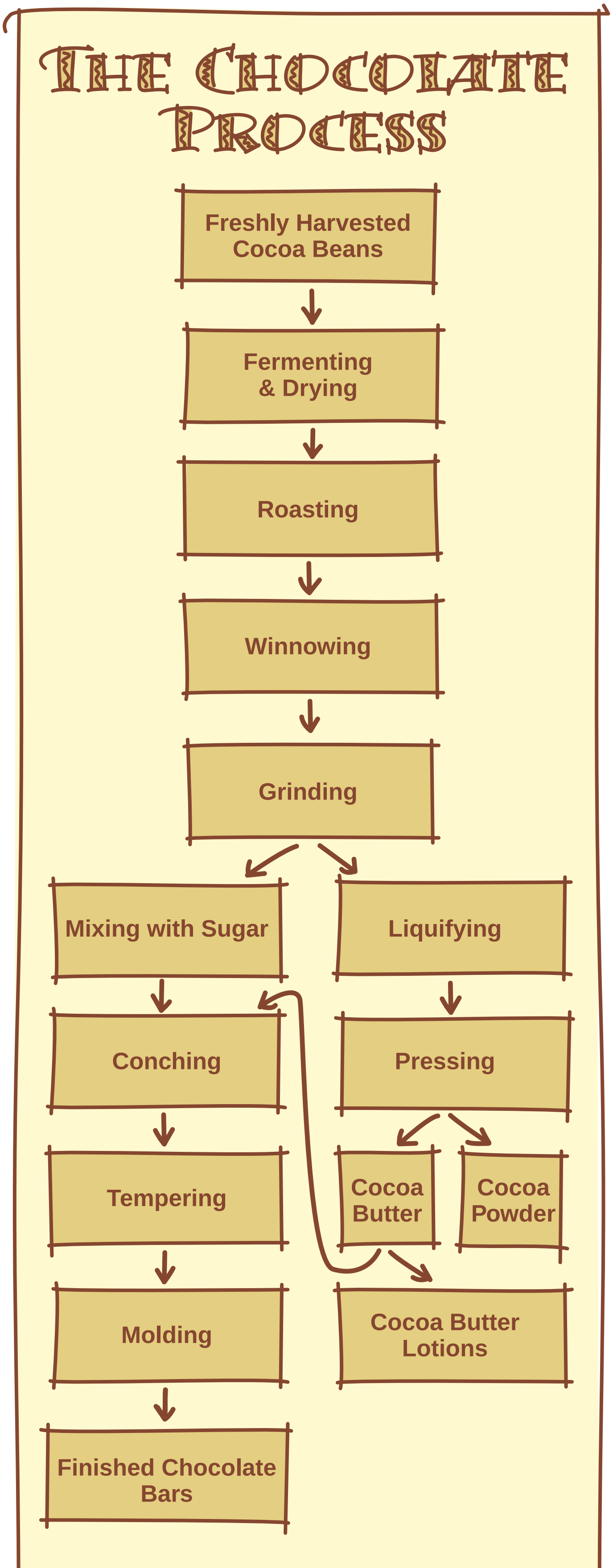
My chocolate dreams and my renewable energy instincts inevitably collided. My new vision was to build a solar powered chocolate factory. We wanted the most efficient machines possible, because chocolate making is a very energy-intensive process for a PV system to handle. For over two years, we experimented with designing our own chocolate making machines, as well as refurbishing a couple of antique machines.

On all these machines, we used DC, permanent magnet motors, which allow efficient direct powering from the PVs or batteries. In my partner Doug's barn in Oregon, we built and tested several generations of machines, including wood-fired roasters, winnowers, grinders, and cocoa butter presses. We tested them by processing cocoa beans we imported from Grenada.

After many months, lots of brainstorming, and a few dead ends, we had a machine line we were happy with, and chocolate we were addicted to. We packed up all our machinery and solar-electric equipment, and sent it on a ship to Grenada about two years ago.

Building the Factory

It was natural to create our little factory in the countryside village that I had lived in over the years. I built a bamboo house in this village, and had created independent appropriate technology projects here, such as teaching solar cooker and hand-powered water



The author pouring cocoa beans into a homemade roaster. A 24 volt DC motor powers the tumbler, which allows the beans to roast uniformly.

pump design in schools and to farmers. I also helped several far-from-the-grid people get acquainted with small photovoltaic power systems for lighting and radio playing in their houses. This village, Hermitage, is also in the heart of the cocoa-growing belt of Grenada.

Together with my two partners, one from Oregon and one from the same village, I started the Grenada Chocolate Company. We began the transformation of an old, abandoned, concrete building into our chocolate "cottage factory." We redesigned the interior of the building to suit our needs piece by piece, simultaneously assembling and wiring our machines.

Because of the hot, humid, tropical climate here, we required air conditioning in two special rooms, one for molding and wrapping chocolate bars, and one for storing chocolate for its crucial aging period. We used efficient, mini-split, ductless-type air conditioners (Lennox LX WM 10F-AFAB).

This type of room air conditioner is common in Asia and Europe. They are relatively efficient because the compressor is located outside the building. They are similar to central air conditioning systems, but are ductless. The coolant simply circulates through pipes in and out of the building, expanding and getting cold in front of a blower inside, but losing its heat in the compressor outside the building.

Refurbished antique winnowing machine, retrofitted with 24 volt DC motors (one motor for vibration and one motor for a powerful fan), removes the outer shell of the roasted cocoa beans.

One interesting thing about designing and implementing our electric system was that we did not have to worry about following codes here in Grenada. There are codes for regular AC wiring, but DC systems are so rare that they never made or adopted any codes for DC wiring and PV installation. We simply did a solid and safe job by our own standards, and we were able to create a suitable system for our unique situation.

Power System

The chocolate factory is on the grid, and there is no provision in Grenada to sell power to the utility. But the grid power is not reliable enough to count on. It can go off for an entire day once or twice a month, and it goes off for fairly brief periods every couple of days. Not only does the grid go off unexpectedly, but the grid transformers around the country are often overloaded. The electric grid in Grenada is designed to run at 230 VAC, 50 Hz. But overloading regularly brings line voltage down as low as 195 V.

Sometimes we need to run the generator even when the grid is on to get a sufficient voltage to run our battery charger and refiner machine effectively. We also have to watch out for very low voltage when the grid first comes back on. We had to replace an electronic temperature control unit on our refiner/conche machine, which we suspect died this way.

We designed most of the factory's loads to run on DC power directly, using the grid to charge our batteries when the PVs cannot provide sufficient energy. When the grid fails unexpectedly, we don't have to worry about any type of backup system switchover to keep our machines moving and prevent our chocolate from burning. Unlike the grid, the batteries won't fail abruptly. We also have some AC loads, such as lights and the air conditioners, which we power either with an inverter, the grid directly, or an engine generator.

PVs & Wiring

We installed sixteen AstroPower, 120 watt PV modules (1.9 KW rated total, at 25°C; 77°F) on our roof, configured for 24 volts. We made our own mounting system out of treated 2 by 3 lumber. Essentially, we installed another set of rafters on top of the corrugated metal roofing, directly over the actual rafters underneath. We lag bolted them together through the metal.

The PVs were first mounted on 1 by 3s the length of the modules, and then laid down and lag bolted across the 2 by 3s. This provided a sturdy mounting and a cooling air gap underneath the modules. It does have the disadvantage of making it less convenient to check the connections in the PV junction boxes.

The PVs are interconnected with #10 (5 mm^2) stranded wire that is tucked underneath the panels to hide it from

Wendy-Ann Edgar pouring sugar into the antique melangeur.

Edmond Brown works the cocoa butter press.
A 24 volt homemade blender (not shown) blends up hot, ground liquid cocoa to feed the press.

the extreme UV. The array is split into two separate 24 V subarrays, each with two #4 (21 mm^2) wires attached. The subarrays each have their own 45 amp DC breaker going into the charge controller in the load center.

The dual breaker system offers the convenience of comparing the total number of incoming solar amps from the two subarrays by turning one off at a time. This is a nice way to gain some instant reassurance that all the PVs are functioning the same and, therefore, properly.

Because the chocolate factory is wired for DC as well as AC, a variety of wiring was used. Several 24 VDC and a couple of 12 VDC circuits for the machines are wired using single conductor, stranded #12, #10, #8, and #6 (3, 5, 8, and 13 mm^2) wire from the load center. Romex type wire was used for the two different kinds of 120 VAC and the 230 VAC circuits.

Balance of Systems

The system also includes four Trojan L-16 high-capacity batteries (395 AH at 6 VDC each), a Heliotrope SolPan 110 load center/control system with a Heliotrope CC-120, 120 amp charge controller; a Quick Charge 60 amp, 24 volt forklift battery charger: and a Honda propane powered engine generator.

The battery bank capacity is relatively small (395 amp-hours at 24 V) because, for now, we don't have enough solar generating capacity to cover the total consumption of the factory anyway. So the batteries get used as a buffer (a voltage stabilizer), powering loads day and night, while being simultaneously charged by some combination of the PVs and the battery charger.

We use a manual-start 5 KW engine generator that we converted to be fueled with propane with a spud/regulator kit. The 230 VAC (our grid voltage here in Grenada) output of the generator is connected through a homemade isolation/transfer system that uses two 60 amp receptacles and one 60 amp plug wired to the grid panel. With this setup, the 230 VAC loads can easily be manually switched between the grid and the generator.

A 2,400 watt Trace modified square wave inverter is powered by the battery bank. The inverter output is wired to a separate 120 VAC, 60 Hz breaker panel. We wired special inverter-powered 120 VAC receptacles from this panel at various places around the building where we need them.

Controls & Warnings

The battery charger cycles on and off automatically as needed, using a power relay and a commercial voltage sensing switch. This sensing switch has two setpoints. We set it to turn the charger on when the battery

Chocolate Factory Loads

DC Load	*Volts*	*Amps*	*Watts*	*Average Hrs./Day*	*Average WH/Day*
Granite stone chocolate grinder	24	40.0	960	8.0	7,680
Inverter (for AC loads)	24	19.0	456	11.0	5,016
Chocolate temper kettle	24	43.0	1,032	4.0	4,128
19 DC CF lights	24	10.5	252	10.0	2,520
2 Vent fans	24	1.3	30	24.0	720
Cocoa bean winnower	24	33.3	799	0.8	599
Cocoa butter press	24	4.0	96	2.0	192
2 Mold cooling fans	24	2.0	48	4.0	192
Cocoa bean roaster	12	5.0	60	2.0	120
Chocolate mold vibrator	12	1.5	18	3.0	54
				Total	21,221

The power wall including the SolPan 110 DC load center, which contains a Heliotrope CC-120 charge controller.

voltage drops to 23 volts DC, and to shut off when the voltage reaches 26 volts DC.

Because some of the loads are running constantly, we don't try to use the AC charger to top off the batteries. The energy used to raise the voltage of the system higher than necessary for powering the loads would just be lost as heat in the motors and batteries.

We also don't want the charger to come on at too high a voltage, so the PVs always get the first chance to power the factory. The batteries seem to stay healthy because, naturally, once in a while we stop making chocolate. Then the PVs get a chance to top off the batteries.

The Heliotrope charge controller has an adjustable voltage regulation setpoint, over which it switches to pulse width modulation mode to keep that voltage steady by controlling the current. Below this setpoint, the charger allows the full current from the PVs to enter the batteries. For the first six months, we had the setpoint at 29 volts. This seemed safe and practical for our Trojan L-16 deep-cycle batteries.

But we found that the batteries were drying fast, needing watering quite often, presumably due to the very high average ambient temperature here. We have since lowered the setpoint to 28 volts to avoid shortening our batteries' lives. We put in an override switch as well, so we can also use the battery charger to top off the batteries in case of bad weather.

The AC charger, used for grid backup, sits atop the vented battery box that holds four Trojan L-16Hs.

An alarm, powered by the battery bank, of course, warns us when the grid goes down. It is activated by a

Two 230 V receptacles allow a choice between utility or generator power. The LED and stereo indicate a hot grid.

The voltage sensors and controls for the low voltage disconnect and AC battery charger.

normally closed relay that is usually held open by power from the grid panel. When the grid goes off, the relay closes the alarm circuit, telling us that we need to watch what is going on and start the generator if necessary.

If a grid outage went unnoticed, the battery bank could be depleted after some hours, and our low voltage disconnect system (LVD) would come into play. For our LVD system, we use another voltage controlled switch and an electric car contactor. After the low voltage dsconnection, if it gets sunny enough or the generator is started and the battery charger comes on, the voltage goes right up, and the contactor turns on the factory.

Not only do we have to be alerted when the grid goes off, but we also need a “grid-back-on-alarm.” Without it, we wouldn’t know when we could stop the generator and save propane. So we installed a fused, 230 V LED outlet directly to the large, grid powered receptacle of the transfer system. When the grid comes back on, this special outlet turns on. Either the lit LED or a radio plugged into the outlet alerts us that the grid is on again.

The Loads

We use several types of electricity at the factory. Our larger DC loads, including the chocolate grinder (melangeur), the tempering kettle, the cocoa butter press, and the winnowing machine, are routed through 75, 75, 45, and 30 amp DC-rated breakers, respectively, in the load center.

We also added two, five-circuit fuse blocks inside the load center. One is used for additional, low power 24 VDC loads such as the roaster’s rotation motor and DC lights. A Solar Converters, 24 to 12 volt buck converter (DC-to-DC voltage converter) powers a few small 12 VDC loads via the second fuse block. The inverter’s DC input is routed through a 175 amp breaker, which is also located inside the load center.

The generator produces 230 VAC at 60 Hz. The air conditioners are 230 VAC, 50 Hz. The AC compact fluorescents (CFs) are 120 VAC, 60 Hz. We are mixing and matching frequencies between several of our appliances except for the AC CFs, which are always powered by the 120 VAC, 60 Hz inverter. Our loads don’t seem to care.

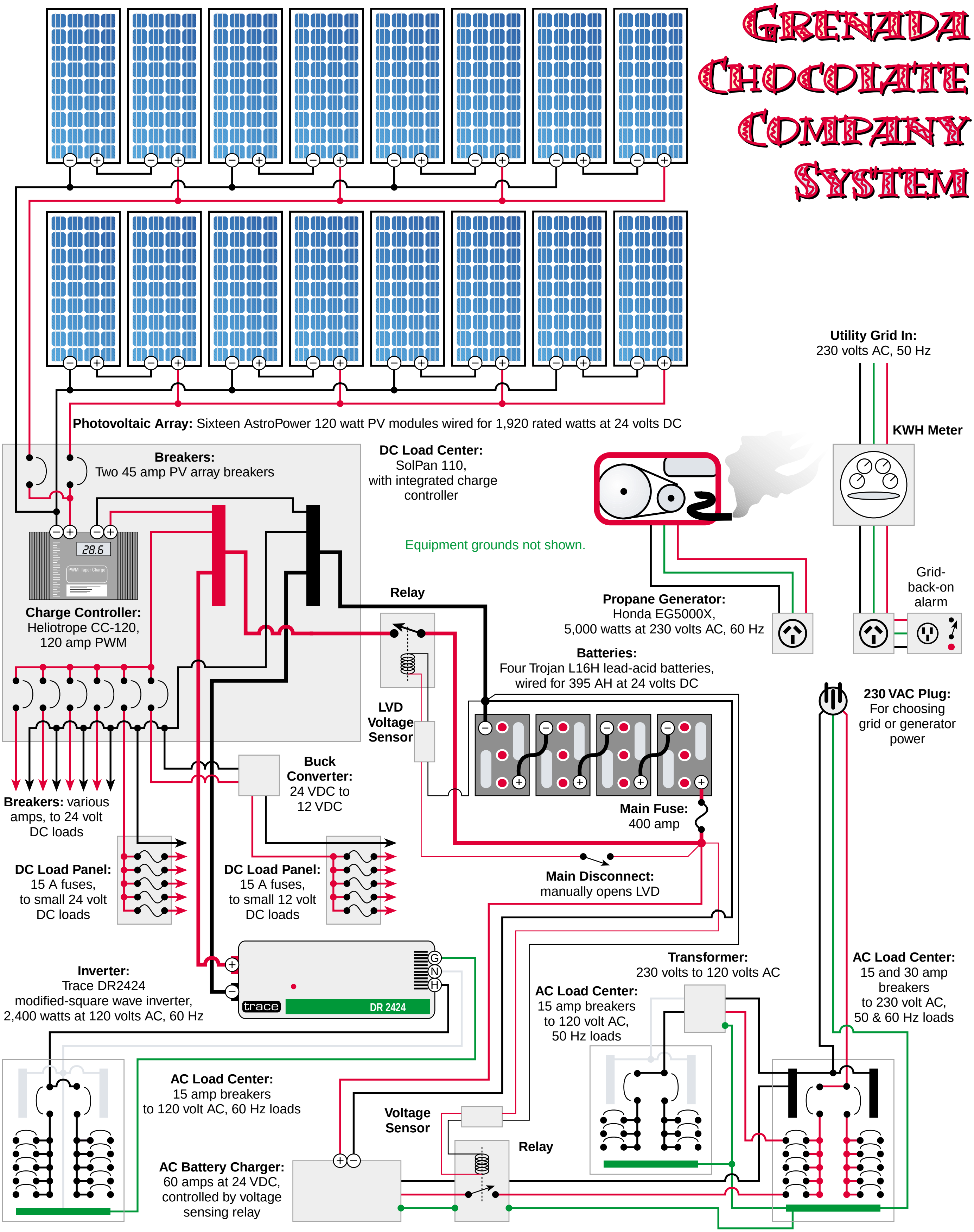
In Grenada, tools and appliances and the like are imported from both the U.S. and Europe, so you never know what you might find. Many houses have 230 to 120 VAC transformers to run their fridges, TVs, stereos, etc. Some of our tools, as well as some of the components we put into our chocolate machines, need 120 VAC.

To cover all situations, we wired the factory with two types of 120 VAC. Some 120 VAC outlets are powered by the inverter, and others are powered by the grid or the generator through a step-down transformer (so we have 120 volts at 50 Hz from the grid or 60 Hz from the inverter).

Some of our lights in the factory are powered by the inverter. Other lights are DC. All the lights are compact

Chocolate Factory System Costs

Item	*Cost (US$)*
16 AstroPower 120 W modules	$8,640
Trace DR2424 modified square wave inverter	1,285
Honda EG5000X generator	1,200
Heliotrope load center w/ controller	1,175
4 Trojan L-16H batteries, 395 AH	840
Quick Charge battery charger	520
2 Solar Converters voltage-sensing switches	300
U.S. Carburetion propane fuel adaptor kit	275
KTA Services electric car contactor	145
Solar Converters buck converter, 24/12 V	140
Charger turn-on relay	32
Alarm activation relay	11
Total	$14,563


Grenada Chocolate Company System
Photovoltaic Array: Sixteen AstroPower 120 watt PV modules wired for 1,920 rated watts at 24 volts DC
Breakers: Two 45 amp PV array breakers
DC Load Center: SolPan 110, with integrated charge controller
Equipment grounds not shown.
28.6
Charge Controller: Heliotrope CC-120, 120 amp PWM
Breakers: various amps, to 24 volt DC loads
Relay
LVD Voltage Sensor
Buck Converter: 24 VDC to 12 VDC
DC Load Panel: 15 A fuses, to small 24 volt DC loads
DC Load Panel: 15 A fuses, to small 12 volt DC loads
Utility Grid In: 230 volts AC, 50 Hz
KWH Meter
Propane Generator: Honda EG5000X, 5,000 watts at 230 volts AC, 60 Hz
Grid-back-on alarm
Batteries: Four Trojan L16H lead-acid batteries, wired for 395 AH at 24 volts DC
230 VAC Plug: For choosing grid or generator power
Main Fuse: 400 amp
Main Disconnect: manually opens LVD
Inverter: Trace DR2424 modified-square wave inverter, 2,400 watts at 120 volts AC, 60 Hz
trace
DR 2424
Transformer: 230 volts to 120 volts AC
AC Load Center: 15 amp breakers to 120 volt AC, 50 Hz loads
AC Load Center: 15 and 30 amp breakers to 230 volt AC, 50 & 60 Hz loads
AC Load Center: 15 amp breakers to 120 volt AC, 60 Hz loads
Voltage Sensor
Relay
AC Battery Charger: 60 amps at 24 VDC, controlled by voltage sensing relay

fluorescents, of course. Our chocolate refiner (conche) machine, the battery charger, and the air conditioners run on 230 VAC directly off the grid or generator.

Four Voltages

With all the various requirements for our factory's equipment, we actually ended up having four different voltages and two frequencies of 120 VAC! The grid and our air conditioners are 230 VAC. Our inverter and our transformer provide us with 120 VAC modified square wave 60 Hz, and 120 VAC sine wave 50 Hz, respectively. We have various components, controls, and tools that use 120 VAC. Some of them prefer 60 Hz, while others would rather have a true sine wave at 50 Hz to operate properly.

Most of the machines and lights use 24 VDC, our system's nominal voltage. But one of the permanent magnet gear motors that we needed was only available in 12 VDC. That's why we installed the 12 VDC fuse block inside the load center. It is handy anyway because a lot of the DC tools and appliances we can find, such as fans, are 12 V.

Being situated on a little island in the sea causes us to end up with motors and other devices imported from all over the world with various voltages. By having all the common voltages, we can cover almost any situation as we continue to tinker and figure out the best way to expand our operation's output. It's a complicated system, and not something I'd recommend in most cases.

Future Solar Plans

Who said it's not practical to power air conditioners with PVs? The mini-split type we use is quite efficient. Our 9,000 BTU per hour unit only draws 970 watts, and cycles off quite often in our small insulated room.

My ballpark estimate is that each air conditioner is on about a quarter of the time on the average, or a total of twelve hours per day for the two units. This gives an approximate total of 11.6 kilowatt-hours per day. With a large 230 volt inverter and another 6 kilowatts of PV, we should be able to solar power the entire factory, including the air conditioners, most days of the year down here in the sunny Caribbean.

Solar Powered Chocolate Cooler

We needed a way to keep our chocolate at about 70°F (21°C) when selling at beach parties. Thermoelectric coolers, commonly used by truck drivers to keep drinks cool, are perfect for use with PVs because they cool mildly and use little power.

A phenomenon known as the Peltier effect causes one side of a thermoelectric module to get hot and the other cold when electric current is applied. When the module is coupled with a heat sink on one side and a heat conductive plate on the other, it acts like a heat pump, keeping the inside of the cooler cool.

We added thermoelectric cooling to a regular cooler (Coleman, US$55) by incorporating an aluminum plate (scrap yard, US$8), a Peltier cooling module (US$15), a block of aluminum (scrap yard, US$6), a heat sink (US$10), and a 12 V muffin fan (US$9) into one wall of the cooler. A square chunk of the cooler wall and insulation was cut out to accommodate the unit. The 2 by 2 inch (5 x 5 cm) Peltier module and the block of aluminum were placed where the insulation was, with the cold side of the module facing in against the aluminum plate, which was mounted on the inside of the cooler.

The hot side of the module faces out against the aluminum block. The other side of the aluminum block contacts the heat sink, mounted on the outside of the cooler, with the fan attached. Thermal conductive compound was applied to all meeting surfaces. A 55 watt Siemens PV module (US$330) is connected directly to the positive and negative terminals of the thermoelectric module and the fan in parallel, using #12 (3.3 mm^2) wire.

The nice thing about a PV powered thermoelectric unit is that the more current available to the module, the colder it will get. When it is sunniest and hottest, we get the most cooling power. The maximum cooling happens at 5.5 amps for this thermoelectric module. So we get less than half its full effect from the single 55 watt PV module, which seems to be enough if we are in the shade. If we need extra cooling power, we could just add another PV module.

Peltier effect cooler and PV panel.

Another difficulty is that we have to store sacks of cocoa beans for months during the off-season. They spoil quickly in this very hot, humid, tropical environment. There is certainly not enough space in our little air conditioned rooms to store cocoa beans. So we plan to get a small cargo ship container and convert it into an independently PV powered, air conditioned, cocoa bean storage unit.

We'll need approximately 2 kilowatts of PV (which will shade the roof of the container as well), another 230 volt inverter, a separate set of batteries, and another mini-split air conditioner. Large PV systems like this are expensive, of course, but if the loans to acquire them are attainable, we see them as buying our chocolate making energy long in advance.

Chocolate Power!

Finally, after years of tinkering, munching on chocolate, and sweating profusely, we have completed the factory and successfully tested all systems. Our little chocolate making cooperative can crank out about 300 pounds (136 kg) of chocolate and cocoa powder every week, enough for the local and tourist markets.

One month after our product launching, we are feeling very encouraged. The foreigners and tourists are impressed with our products, since they are used to dark chocolate. Grenadians themselves are just getting used to the idea. Only low quality milk chocolate has ever been imported, and we are the first chocolate company in Grenada. It's fun that people here can finally enjoy the luxury of high quality chocolate after supplying the fancy European chocolate companies with cocoa beans for over a century.

Grenada's cocoa is some of the strongest in the world. It is also particularly clean cocoa, very rarely sprayed with pesticides. Eventually we will export our chocolate, but for now, we will just be keeping up with the local market. We are probably the smallest chocolate factory in the world, and perhaps the only solar powered one.

Doug Browne and Wendy-Ann Edgar wrap finished solar powered chocolate, and try not to eat too much.

Access

Moth Green, The Grenada Chocolate Company, Ltd., Hermitage, St. Patrick's, Grenada, West Indies
473-442-0050 • moth@grenadachocolate.com
www.grenadachocolate.com

AstroPower, Inc., Solar Park, 461 Wyoming Rd., Newark, DE 19716 • 866-218-2797 or 302-366-0400
Fax: 302-368-6474 • sales@astropower.com
www.astropower.com • PV modules

Trojan Battery Company, Inc., 12380 Clark St., Santa Fe Springs, CA 90670 • 800-423-6569 or 562-946-8381
Fax: 562-906-4033 • marketing@trojanbattery.com
www.trojan-battery.com • Batteries

Xantrex Technology, Inc., Distributed Residential and Commercial Markets, 5916 195th St. NE, Arlington, WA 98223 • 360-435-8826 • Fax: 360-435-2229
inverters@traceengineering.com • www.xantrex.com
Inverter

Solar Converters, Inc., C1-199 Victoria Rd. S., Guelph, ON, Canada, N1E 6T9 • 519-824-5272
Fax: 519-823-0325 • info@solarconverters.com
www.solarconverters.com • Voltage controlled switches (model VCS-2) and buck converter, 24 to 12 volts (model EQ 12/24-20)

KTA Services, Inc., 944 West 21st St., Upland, CA 91784 • 909-949-7914 • Fax: 909-949-7916
www.kta-ev.com • Electric car contactor and main battery fuse.

Quick Charge Corp., 1032 S.W. 22nd St., Oklahoma City, OK 73109 • 800-658-2841 or 405-634-2120
Fax: 405-632-5667 • contact@quickcharge.com
www.quickcharge.com • Forklift battery charger

Honda Power Equipment Group, 4900 Marconi Dr., Alpharetta, GA 30005 • 800-426-7701 or 770-497-6400
Fax: 678-339-2670 • www.honda.com • Generator

U.S. Carburetion, Inc., HC79, Box 130, Building B-1, Canvas, WV 26662 • 800-553-5608 or 304-872-7098
Fax: 304-872-3359 • sales@uscarburetion.com
www.propane-generators.com • Propane fuel conversion spud kit

Leeson Electric Corporation, PO Box 241, Grafton, WI 53024 • 262-377-8810 • Fax: 262-377-9025
leeson@leeson.com • www.leeson.com • Motors

Scott Motor Company, 2401 S. Virginia St., Reno, NV 89502 • 888-550-0270 or 775-332-4000 Fax: 775-332-4005 • info@scottmotors.com www.scottmotors.com • Motors

W. W. Grainger, Inc., 100 Grainger Parkway, Lake Forest, IL 60045 • 847-535-1000 postoffice@grainger.com • www.grainger.com Dayton motors

McMaster-Carr Supply Company, Inc., PO Box 740100, Atlanta, GA 30374 • 404-346-7000 • Fax: 404-349-9091 atl.sales@mcmaster.com • www.mcmaster.com Various relays, pulleys, sprockets, and other assorted machine-building supplies

Lennox Air Conditioning, PO Box 799900, Dallas, TX 75379 • 800-9-LENNOX or 972-497-5000 Fax: 972-497-5331 • www.lennox.com • Mini-split ductless air conditioners

Backwoods Solar Electric Systems, 1395-HP Rolling Thunder Ridge, Sandpoint, ID 83864 • 208-263-4290 Fax: 888-263-4290 • info@backwoodssolar.com www.backwoodssolar.com • Siemens PV module for solar cooler, SolPan load center, and CFs

Marlin P. Jones & Assoc., Inc., PO Box 12685, Lake Park, FL 33403 • 800-652-6733 or 561-848-8236 Fax: 800-432-9937 • mpja@mpja.com • www.mpja.com Thermoelectric cooling module, muffin fan, heat sink