Part 1

Using the TriMetric (or other battery system monitor) to maintain your battery system, conserve energy and troubleshoot system problems.

Newly revised for TM-2020

Available on the Internet at **www.bogartengineering.com**

Part 1: (Sections A-C) **For beginners:** Volts, amps and amp-hours are defined and their use is explained in a renewable energy system. Basic lead acid battery care is described.

Part 2. Intermediate/advanced: (To be written later) Troubleshooting renewable energy system problems. Analyzing system performance. Battery capacity, resistance and efficiency measurement. Checking charge controllers. Charging batteries. Other battery types. Other topics.

Bibliography on renewable energy systems (to be compiled): A bibliography of catalogs and books available related to powering a home with renewable energy.

Comments and suggestions for improvement are welcome.

How to get what you want from this guide.

For **day-to-day usage** of your TriMetric (or other system monitor) read **Part 1, Sections A-C.** Section B is *necessary background,* and section C contains *specific suggestions* for use.

For **more advanced information** on troubleshooting a renewable energy system problems, read **Part 2, Sections D-F.**

If you want the minimum information to understand how to use the TriMetric, read the parts of **sections B-C that are not labeled "optional".**

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Part 2: To be completed later.

A. Renewable energy systems are practical now.

It is quite practical today to use solar or other renewable energy for powering a home--much more so than 15 years ago. Some reasons for this are:

Availability of reliable high efficiency inverters that convert battery power at high efficiency to AC power usable by ordinary electrical appliances for 24 hours a day.

Lower energy requirements of many electrical devices--such as TV's, computers and electric lighting.

Cost of solar panels that can convert light to electricity is going very gradually down, while grid power has gone gradually higher. As grid power costs go higher in the future even more people will find renewable energy practical.

Lack of subsidies to extend grid electricity. In many cases when electric lines must be run a significant distance to reach the grid--one-half mile-- if your energy requirements are not too great it is cheaper to use "off the grid" systems because of the high cost of connecting to the grid.

Limitations of such systems. Despite their practicality for many people, there are some limitations that must be understood by users of such systems:

Higher cost per kW-hr: Electricity from small renewable energy systems still costs quite a bit more per kilowatt hour of energy than that produced from the electrical grid--from 3 to 10 times more expensive--so conservation becomes more important. However, if a small number of high energy using devices are avoided, such as space heaters, hot water heaters and air conditioners, this is not a serious limitation. It is even practical to run some heat producing appliances provided they don't run too long--such as microwave ovens, toasters or hair dryers. However it is important to be mindful of electrical usage; a battery system monitor such as the TriMetric that shows "amps" of current draw from the system is very useful to increase user awareness of energy consumption.

You need a site that has solar, wind or hydroelectric energy available. Not every site has a suitable source of energy. If solar energy is available, energy from photovoltaic panels is usually the cheapest and most reliable. Hydro power or wind power is also possible for those sites that have sufficient wind or a stream available.

May not supply extremely high power The grid can easily supply either a little power or very much power, however a renewable energy system of reasonable cost is somewhat limited in its ability to supply maximum energy demand. You can easily power a toaster for a few minutes--but you may not be able to run your washing machine and microwave at the same time unless you have a larger system—however these larger systems are becoming more common so that now this may not be a practical limitation.

Power needs to be used within a week of the time it is produced. With grid power you can choose to use a little power in one month, and a lot of power the next month. A renewable energy system usually has a certain amount that is delivered every day--and although it can be easily stored in batteries for a short time--on the order of days--within the limitation of that storage it must be used as it is produced.

Generator is useful to fill in the gaps These last two disadvantages can be significantly overcome by using a petroleum powered (gasoline, propane or diesel) generator to supply power for the occasional high load and to make up for periods of extended cloudy weather that would limit solar production. However it is generally an important objective to minimize the time that a generator is running to minimize the noise, pollution, and higher cost per kW-hr of the generator compared with solar energy production. As will be explained below in section C-3, a system monitor that measures "amp-hours" is a very useful tool to plan generator charging to minimize generator run time.

More user knowledge needed: If you use grid power, you don't need to know much more than the location of the switch and occasionally how to flip a circuit breaker and the location of your checkbook when the electrical bill arrives. A renewable energy system, even though often *more reliable* than grid power, needs a user that has minimal knowledge about battery care and other system maintenance, as well as more awareness of energy usage and conservation. A system monitor is useful to help supply this kind of information and increase user awareness of their system, as well as helping to locate the occasional problem. Incidentally, for maximum usefulness the battery system monitor should be located where the occupants of the living area can glance at it easily--for example the kitchen, not in a garage or distant battery room.

B. Basic TriMetric measurements and terminology: volts, amps, “battery % full” and amp hours. Definition of "battery capacity" and "battery state of charge" A little information on lead acid batteries. The purpose of this section is to familiarize you with the basic TriMetric measurements and to help you become familiar with some other background useful to understanding the basics of your energy system.

How to access the measurements on the TriMetric TM-2020: Successively pushing the "**SELECT**" button on the TriMetric switches the reading from "**volts**" to "**amps**" and then "**Battery % full**". Pushing "**SELECT**" again puts the meter into the "blank" display. Pushing “**SELECT**” again cycles back to “**volts**” again. In addition, five “extra” data functions, shown on the bottom of the front panel, which are used more occasionally are available by holding the “**SELECT**” button down for 3 seconds while viewing any of the above, until “**AH**” appears in the display. Releasing the “**SELECT**” button will now show the “**Amp-hours from full**” display, which will periodically alternate with “**AH**”. This is the first of the “extra data” functions shown on the bottom part of the front panel. The rest of these are accessed by now pushing the “**SELECT**” button repeatedly. The six extra data displays show (1) Amp-hours from full (“AH”) (2)How many days since the battery has been fully charged(“dSC”) (3)How many days since the battery has been equalized(“dSE”) (4)The “cumulative, lifetime amp-hours discharged”)(“cAH”) (5)Highest battery voltage (since last reset) (bHI) (6)Lowest battery voltage (since last reset.) (“bLO”)

1. Using amps: Amps, or more properly, **amperes**, are a measure of electrical **current**, or the *rate* at which electricity flows through a wire at a certain point, (analogous to the gallons/minute of water flowing in a pipe.) The higher this rate, the more rapidly electrical energy flows. Electrical current flows from your batteries into a load at a certain ampere rate (for example 5 amperes) and the higher the rate the more quickly the batteries will be discharged. (As will be mentioned soon, *volts* are a measure of how hard that flow is being pushed, analogous to water *pressure* in a pipe.) Current is usually measured by breaking the wire and inserting an *ammeter*, which completes the circuit and measures the flow. Current supplied by the solar array when the sun is shining has a certain number of amps (typically 2 to 5 amps per solar panel in full sun), and electricity is consumed by the electrical loads at a certain number of amperes (from 0.1 to over 100 depending on the load) when they are operating. The value to you of measuring amps is that it enables you to see how much energy is entering or leaving the batteries (depending on whether they are being charged or discharged). You can check that your solar array or other charging source is working properly and also become familiar with how much current your electrical loads are using which is important to know for conservation awareness.

Optional: A shunt is used to measure amps. With a battery monitor such as the TriMetric, which measures very large amounts of current, current (amperes) is measured by permanently wiring a *shunt* (which is like a wire with an precisely known resistance) near the batteries at the point where you want to measure the amps--usually right into the negative terminal output connection from the batteries. The TriMetric measures all the current that flows through the shunt. The reason it is connected near the batteries is that the battery power wires must be kept quite short to avoid electrical losses because they carry such high current (often over 100 amps.) Small sensing wires connect from the shunt to the TriMetric, which converts a very small voltage to a current reading that the TriMetric displays as amps which you read on the display. For example, when using the 500 Amp/50 mV shunt (called the "H" shunt) one amp flowing through the shunt will result in one ten-thousandth of a volt across the shunt, which is measured and displayed by the TriMetric as 1 amp. Although it is easily possible to set up the TriMetric to measure amps at other points in the circuit, to measure *only* solar array current, or *only* load current, with renewable energy systems it is usually set up to measure the "net" amps into or out of the battery by inserting the shunt in the negative terminal from the battery, so all the current flowing in or out of the battery is measured. (Often called "net" battery current.) Set up in this way, the TriMetric can also use the “Batt % Full” or "amp-hours" displays to show how full the battery is as will be explained more fully later.

2. Use of volts: The second of the three main numbers that the TriMetric battery monitor measures is volts across the battery or "electrical potential" or electromotive force (e.m.f.) of the battery. This is a measure of the force with which the electricity is pushed by an electrical source such as a battery, solar array or generator into an electrical load. Not surprisingly, in almost all cases if the amount of force, or number of volts increases from the source, the amperes or flow through the load will increase because the force behind the electricity has increased.

It is useful to measure "volts" because it is a basic electrical measure of the battery--or the solar array--or charger. It's like measuring pulse or blood pressure--and is especially useful as a diagnostic tool, especially when used in conjunction with an "amps" measurement. However it requires more understanding and interpretation than either "amps" or "amp-hours" to provide useful information--so it will not be of as much interest to the casual user of the electrical system as it would be to a technician trying to check out an energy system. The following table shows what happens to battery volts with lead-acid batteries under some conditions of use.

For Wet Cell Lead Acid Batteries:	VOLTS:	
	12 Volt system	24 V system
Battery overcharged or during final stage of equalize charge.	over 15.0	over 30.0
Battery near full while *charging* (depends on amps and temp)	14.4-15.0	28.8-30.0
Battery near empty while *charging* (depends on amps and temp)	12.3-13.2	24.6-26.4
Battery full with light loads (depends on amps and temp)	12.4-12.7	24.8-25.4
Battery full with heavy loads (depends on amps and temp)	11.5-12.5	23.0-25.0
Battery standing (0 amps for 6 hours) 100% (full)	12.7	25.4
" 80% charged	12.5	25.0
" 60% charged	12.2	24.4
" 40% charged	11.9	23.8
" 20% charged	11.6	23.2
" 0% (empty)	11.4	22.8
Battery nearly empty while discharging (depends on amps and temp)	10.5-11.5	21.0-23.0

Table notes: When a range of voltages is shown in this table, the voltage will be *higher* when more current goes in the battery (charging), and *lower* as more current leaves the battery (discharging). In addition, the temperature affects the voltage as follows: while *charging*, a lower temperature will *increase* the voltage. (For example, while charging a 12 V lead acid battery, the voltage rises approximately 0.9 volts from 77°F to 32° F.) While *discharging*, a higher temperature will *increase* the voltage. There is little temperature effect while the battery is standing being neither charged or discharged.

Table 1

As can be seen, one important factor influencing the "volts" reading is the "state of charge" of the batteries. ("State-of-charge" will be defined again later, but it means "how full" the batteries are.) Very generally, the battery voltage gradually goes up as the batteries acquire more energy through being charged, and goes down as energy is removed. Often simple "battery full/empty gauges" which are intended to show how full the battery is use only this volts measurement. Variations on this theme are simple voltmeters that control green/yellow/red indicator lamps, often conditioned by a time delay that give a rough indication of "state of charge". The difficulty of using volts to accurately measure state of charge is that the voltage reading is also affected by *how many* amps are being used to charge and discharge. If the batteries have not been either charged or discharged for awhile (several hours) the "volts" reading can be used to get a good idea of "state of charge". However if the battery is being discharged by a load, the "volts" reading will be pulled down depending on how many amps are being discharged. If you start charging them again, the voltage will immediately be pushed up by the charger, again, depending on how many amps are charging.

However, there are two extreme situations where the "volts" reading is particularly useful to tell the battery state of charge: one is while the batteries are *nearly fully charged* while they are being charged. In this case the battery voltage will start to climb more rapidly, and show a value (for a 12 Volt system) of from 14.2 volts or higher. (Double this for 24 V systems.) At the other extreme, while discharging, the voltage reading can be relied upon to show that the batteries are nearly depleted of energy, when the reading goes below 11.2 volts (for 12 volt systems--double for 24 volts), and will start to decline more rapidly from there. But as mentioned, when the battery is in intermediate states of charge the voltage curve is “flatter”, meaning that the voltage doesn’t change as much, so it doesn’t work well to gauge the "state of charge". As we will describe very shortly, the "**amp-hours from full**" measurement, and the “**Battery % Full**” display--which is based on the “**amp-hours from full**”--are much more reliable indicators of "state of charge" in this intermediate region.

Table 1 (above) shows the normal range of "volts" for various conditions of battery "state-of-charge", charging or discharging current, and temperature.

An important use of the "volts" reading on the monitor is to check that the charging system regulators are working properly. The charging systems (which includes the system "charge controller") should charge the battery volts up to a certain point, then stop charging or the batteries can be damaged by excessive charging. Similarly, if the voltage does not rise high enough the batteries can be chronically under charged, which will result in "sulfation" and thereby shorten battery life. The TriMetric can record and save the "highest" voltage which occurs while finishing a charge, so it can easily allow you to occasionally check this value of maximum charge voltage, and therefore check that the charge controller is adjusted and operating properly. The easiest way to check this maximum value is by using the “**maximum voltage**” “**bHI**” display, which is an “extra data” function shown on the bottom of the panel. Before using it for this purpose you should use the “select” button to switch to this display, reset the voltage to the “present” battery voltage by holding down the “**RESET**” button until the display flashes for 3 times. It will now track the battery voltage as it goes higher, but will not go down as the voltage goes down, thus showing the **maximum** voltage that the batteries attained until you again manually “**RESET**” the value. After the solar array or other charger has finished charging the batteries you can then check this display to see the maximum voltage attained.

3. Using Battery % Full. This display shows how much energy is left in your batteries. Here is a quick synopsis of how this measurement is made, to be more fully explained in the next section: The TriMetric senses when the battery is fully charged when the“volts” goes sufficiently high, and the “charging amps” become sufficiently low. It then resets the “Battery% Full” reading to “FUL” or 100%. As energy is removed the meter measures the “amp-hours” removed from a full battery, and during any subsequent charging measures the “amp-hours” returned to keep track of how much energy is in the batteries. The “Battery % Full” is based completely on the “amp-hour from full” measurement, and also on the value of total amp-hours (“capacity”) of your battery set which you must program into the TriMetric. Since the “Battery % Full” display is based on “amp-hours” it is important to understand “amp-hours” first.

"Ampere-hours from full" and "Battery % Full". As was mentioned already, the most important function of the "amp-hour from full" display (which is an "extra data" function shown on the panel) is to measure the energy content of the batteries, especially when the battery set is *not* at the extreme high or low end of charge or discharge, which is the case most of the time. This is particularly useful to plan your electrical usage avoid over discharge of the battery set and to know when to turn on the generator. This will be described later in explicit detail in section C3. **Amp-hours** is a measure of accumulated amps--or amps multiplied by time (called "charge"). For example, if energy is being taken from the batteries such that the "amps" display on the TriMetric shows -10 (minus 10) amps, the "amp-hour from full" display will gradually decrease until after one hour the amp-hour display will be exactly 10 less than it was, indicating that 10 fewer amp-hours are stored in the battery. Similarly, for every hour that the display shows +10 amps, (when the batteries are being charged) the TriMetric will add *almost* 10 amp-hours. (The "almost" has to do with "efficiency factor" and will be explained shortly.) Here's how the TriMetric keeps track of how full the battery is: (1) the battery must be fully charged, as a starting reference point. (2) The "amp-hour from full" number is then reset to "000" amp-hours, and the "Battery % full" display is reset to "FUL" or 100% (either manually or automatically, as will be soon described) which indicates a *fully* charged battery. From there as the battery is discharged the amp-hour display keeps track of the amps leaving, by counting down to show a gradually *more negative* value, so -40 amps (or 40 amps discharging) for 1/2 hour would *subtract* 20 amp hours from the total, giving a total of minus 20 amp-hours--meaning that the battery is *20 amp-hours away from full*. Eventually after removing as many amp-hours as the battery holds, the battery becomes discharged (which means that the battery volts would have dropped too low to be useful.) At that point the "amp-hour from full" display would have a (negative) value which is equal to the number of amp-hours required to completely discharge the battery starting from a fully charged state--which is called the **capacity** of the battery system. The **capacity** (in amp-hours) of the battery is the total amount of electricity, (or charge) that the battery can hold. If you use the "A-hr from full" display you will need to know what the capacity of your battery system is (in amp-hours) to use the amp-hour display to determine when your batteries are fully discharged. (If you don't know this value, ask an energy system expert or dealer. --Eventually a section in Part 2 of this guide will describe how to determine it.) When the "amp-hour" (negative) number equals the battery capacity, you are out of power. However the amp-hour display is not ordinarily used to determine that you are *completely* out of power (the "volt" reading is more useful for that). Its value is to let you know about how much energy you have left *well before* your batteries are completely depleted, so you can plan your electrical usage so you don't normally get to the point of over discharging the battery set.

The Battery % full display is similar to "amp-hours from full", except that it already incorporates the battery capacity information. It reads "Ful" or 100% when the amp-hour reading is "0.00" and reads "LO" or "0%" when the (minus) amp-hour reading equals or exceeds the entered battery capacity. You will need to program in the correct capacity of your batteries into the TriMetric for this function to read correctly. The "Amp-hours" or "Battery % full" information is also very useful to plan generator usage to minimize running time, as will be described specifically in section C3. Incidentally, usually it is a good idea to enter a value of capacity that is less than the "capacity" value advertised by the battery manufacturer. Then the "% Battery full" display will show a conservative value (lower than actual) battery state of charge. Also, the battery manufacturers tend to be optimistic when rating their batteries—and their number only applies after the battery has been <u>really</u> well charged, and when the battery is 77 degrees f or higher—which usually won't be the case in your practical system.

Charge efficiency factor: Since batteries aren't perfect storage devices, you can't get back all the energy you store into it--some is lost. The TriMetric compensates for this by an approximation which doesn't count the amp-hours *charging* quite as much as the amount discharging. For example, if you *discharge* the battery at -20 amps for 5 hours, the "amp-hour" reading will always become more negative by exactly 20 x 5 =100 amp-hours. But when you *charge* the battery at 20 amps for five hours, the number will go positive by *slightly less* than 100--typically 94 to 98 amp-hours. How much the "charging" energy is discounted may be set by you to approximate your system, depending on the battery type and age-- and it is called the "charge efficiency factor". If 100 amp-hours of charge are added to the batteries, but only 96 amp-hours are added to the "amp-hour" reading, this represents an "efficiency factor" of 96%. Lead-acid batteries are quite charge efficient, and for these this number is pretty high--typically 94-98%--and we recommend if you have new lead-acid batteries to set it to 94% as a good approximation. Setting it to 94% is usually *conservative* which should cause the meter to err slightly on the side of indicating a little less energy than you really have.

Optional note for the technophile on efficiency: Some people are surprised that the "charge efficiency factor" should be so high at 94-98%. There are two reasons for this. One reason is that "Energy efficiency", which is often quoted for lead acid batteries at 75-85%, is frequently confused with "charge efficiency" which we are talking about here. "Charge efficiency" of a battery is the ratio of *amp-hours* required to charge a battery, compared to the *amp-hours* that can be removed later. In contrast, "energy efficiency" of a battery is the ratio of the amount of total *energy* required to charge the battery, compared with the amount of *energy* you get out when discharging. (Energy =volts x amps x time) Energy is measured in "watt-hours" or "joules" (which is the same as a watt-second). Energy depends not only on amp-hours, but also takes into account that you don't get as high a voltage out when discharging a battery compared to the voltage required to charge the battery. This is why the energy efficiency is less than the charge efficiency. The other reason that the "charge efficiency factor" entered in the TriMetric is high is that the number entered is not the true overall "charge efficiency" factor of the battery, since overall charge efficiency needs to also take into account the charging at the very top of charge, when the battery is least charge efficient since some of the charge going in is causing the battery to convert water to hydrogen and oxygen instead of going into useful energy. The number entered in the TriMetric is the charge efficiency *excluding* the top end of charge; and when this is excluded the lead acid battery is very charge efficient. Incidentally, this is also why amp-hours work so well to measure the battery state of charge

State of charge and Depth-of-discharge. These are percentages indicating how full or empty the battery is. "State-of-charge" is the opposite of "depth of discharge". A fully charged battery has a "state-of-charge" equal to 100%, and a "depth of discharge" =0%. When empty, these percentages are reversed. For example, if the capacity of the battery system is 200, and the amp-hour reading is minus 20, the batteries are at 90% state of charge or 10% depth of discharge. The “Battery % Full” display is designed to show you “State of Charge.”

How the TriMetric determines that the batteries are charged: We mentioned that ordinarily the meter automatically resets the amp-hours to zero, and therefore “Battery % full” to “full” or “100” each time the battery is fully charged (unless this feature is programmed off). The question is: how does the TriMetric determine that the battery is charged? After the discussion of battery volts, it shouldn't be surprising that it senses the battery voltage (and also current.) As was mentioned before, when batteries are charged the voltage on the battery set gradually rises. At the same time the charging current (amps) usually declines. The TriMetric measures both amps and voltage, and when the voltage *exceeds* the programmed voltage setpoint, (adjustable by the user, often set to 14.4 volts in 12 V systems--double for 24V systems) and the "amps" is *less than* the current setpoint, (which you may adjust) the meter assumes that the battery is charged. The current setpoint (in amps) is ordinarily set from (C÷50) to (C÷20), where C=battery capacity in amp-hours. After this point is reached, the meter announces this by flashing the "charging" lamp. When the batteries again begin to discharge, the meter resets "amp-hours" to zero and resets the “Battery % Full” to “Ful”. At this time the “Days since Charged” display (an “extra display” shown at the bottom of the front panel) is also reset to 0.00 days.

From this point, as the batteries are discharged and charged, the meter tracks the amount that goes in and out of the battery "bank" like an accountant, and shows the balance as the number of "amp-hours" away from full charge, and hence the “Battery % full”. This is a pretty good way to judge how full the batteries are--it gives a number that is accurate to 5-10% (when the charged parameters are correctly matched to the charging system, as described in section E.1) This is quite adequate for a practical system--and is typically much more accurate than monitors that measure only battery voltage, which is another way to get a very rough idea of how full the batteries are. Incidentally, this is the *system* accuracy for a practical system with lead acid batteries, not the TriMetric amp-hour measurement accuracy, which is much more accurate at ±1%.

However after many days when the batteries are not fully charged, the meter can gradually lose track of the exact charge state. For this reason it is **necessary to periodically resynchronize the battery set by recharging** which resets the amp-hour number to 0, and the "Batt. % Full" to "FUL". This is not only a good idea for the sake of meter accuracy--it is also *necessary* to keep lead-acid batteries in good condition to fully charge them occasionally. Once a week is a reasonable rule for both reasons. The "Days since Charged" display (an "extra display" shown at the bottom of the front panel) allows you to see how long ago (in days) since the TriMetric detected that the batteries were fully charged.

"Battery reminders" display: Another feature of the TriMetric is the "battery reminders" display, which has three different functions. One function (the "days since charged" display) allows you to set up the meter to remind you to fully charge the batteries after a certain number of days have passed. You can set the number of days, for example, to 5; then when 5 days have passed since the TriMetric has sensed that the batteries have been fully charged the "battery reminders" lamp will blink, and about every 12 seconds the numeric display will flash a "Ch.F". It will continue the occasional reminder until you recharge the batteries—or if you want to turn it off you can go the "Days since Charged" display and manually reset the "Days since charged" to 0. If you want to turn this reminder function permanently off, you can program "OFF" into the number of days between reminders.

Another function of the "battery reminders" display can show you when the battery voltage gets too low. When this occurs, the "battery reminders" lamp will blink, and about every 12 seconds "B.Lo" will flash in the display. You can set the desired low battery setpoint voltage, or turn off this reminder if you like.

The third function of the "battery reminders" display is to remind you when to "equalize" the batteries. Equalization will be described below, in section C2. The TriMetric instructions describe in more detail how to set up these functions.

Optional: How to measure total (solar or other) input amp-hours: As mentioned before the most common way to wire the TriMetric is to connect it to a shunt that measures net current in or out of the battery. Some people may want to use the TriMetric to measure only the total solar or wind input amp hours from their source to measure, for example, daily solar production. This can be done by wiring a shunt in series with solar (or other) input wire, on the negative side, so that only the desired current to be measured passes through the shunt. The "amp-hour" display will then record the total input amp-hours and amps. In this case the "efficiency factor" should be set to 100, and the "automatic reset" of amp-hours should be programmed "off". It's also possible to arrange a switch to connect the TriMetric to either one shunt or the other. Then you can switch from "net" battery current to just input energy--so occasionally throughout the year you can temporarily switch to check the solar (or wind) input for a day to check out total daily energy production. However you'll then lose track of battery amp-hours until you switch back and resynchronize with the batteries again by fully charging them. (Or of course you can wire two TriMetrics and have both all the time.)

Optional technical note: Why measure "amp-hours", not energy? Some people familiar with physics or engineering principles may ask why "amp-hours" are used to keep track of energy in the battery. Why not use energy directly, which is watt-hours? The answer to this is that for batteries, watt-hours is a less stable measure of battery electrical content than "charge" or amp-hours. "Watts" depend on the product of volts and amps entering and leaving the battery. But the number of volts depends to a great extent on *how fast* the charging or discharging is taking place, as well as temperature. Therefore the energy you put in with charging is greater if you charge fast (resulting in higher volts) even when the amp-hours delivered and the battery chemical change is the same. Also, lower temperature results in a greater difference between "charging" voltage and "discharging" voltage. The chemical change in the battery however is dependent quite directly on the charge ("amp-hours") transferred. -When the batteries are being charged, but before they have reached a nearly full charge, (and not "gassing") almost all of the amp-hours go into direct chemical conversion, which is almost completely reversible on discharge. (96% or higher is common for lead-acid chemistry *when they are not at top of charge.*) Similarly, for a battery at the same chemical state at "full charge", the total energy you get out upon discharge is greater if the discharge is at lower amps, since the resulting "volts" at the load will be higher during discharge. Also this is why batteries are usually rated by "amp-hours", not "watt-hours".

A few comments on lead acid batteries. There are two subtypes of lead acid batteries, of which the most common is the standard "liquid electrolyte" type. The other type is the VRLA ("valve regulated lead acid") batteries, sometimes called (optimistically) "maintenance-free". The difference is that the former type has a battery cap for each cell, which requires occasional addition of distilled water--which the latter type does not--hence the name "maintenance free". However it is a mistake to think that a "maintenance free" battery needs no maintenance at all. If they are frequently overdischarged, or over or undercharged they will give disappointing performance. If you have the most common type of lead acid battery, (liquid electrolyte), periodic maintenance must include occasionally checking water levels in the batteries. However, in trade for that disadvantage, they have the advantage of lower cost, and not being quite so particular about how they are charged. *If you have the "maintenance free" type of battery, it is very important to adjust the battery charger voltage (both generator charger and renewable energy charge controller) carefully according to the battery manufacturer's instructions or your batteries could be damaged. If you are not sure, check with your dealer.* The TriMetric "extra data" function that measures maximum battery voltage, can be used to check that the charging circuit is working correctly.

C. Basic everyday TriMetric operation.

After you understand the information and terminology above, you are ready to understand the specific suggestions that follow describing how to use the meter in everyday operation to utilize your energy system better. The three topics to be covered in section C are:

C1. Using the TriMetric for energy conservation.

C2. Using the TriMetric to properly care for batteries.

C3. Using the TriMetric to minimize generator usage.:

Numbers you need to know: To make best use of your monitor you must be sure you know some important numbers related to your system. If you are not sure how to determine them yourself, ask someone who is qualified to get these numbers.

Battery capacity of the system is about ____________amp-hours. If you don't know how to determine this, ask your dealer or other energy system expert. This number should be entered into the TriMetric as the "battery capacity" as described in the TriMetric instructions for the "Battery % full" display to read correctly.

Generator charging amps: may vary with battery voltage, so check it at a "nominal" voltage, between 13 and 14 for 12 volt systems, or 26-28 for 24 volt systems. Note the approximate voltage as well as the amps: ______amps at _____volts. (The charging current often goes down as the voltage increases.)

Solar charging amps: Obviously will vary with time of day, so check when sun is about maximum. It may also decrease as temperature rises, so note the temperature. Higher battery voltage may also decrease charging current, so note battery voltage for reference. Charging current is ________amps at ________volts . Outside temperature ________.

Normal charging amps of any other charging sources:

Approximate energy production (amp-hours) in one sunny day. Summer:_____
Winter:___ Of course this depends on the season, so it is good to know the extremes. The

approximate total solar production per day is useful to know for minimizing generator usage, as described below.

C1. Using the TriMetric for energy conservation.

Be knowledgeable about how much energy your appliances use: Use the AMP reading to familiarize yourself about how much power various electrical loads use on your system. First turn the appliance off, and note the "amp" reading. Then turn it on to find out how many more amps are being used. The difference in the two readings is the amount the appliance takes. You might want to write down some of these numbers when you first use your TriMetric. You can think in terms of "amps", or if you prefer "watts" (by multiplying the amps reading by 12 or 24, depending on your system voltage.) The important thing is to develop an intuition about the *relative amounts* of energy required by different items--for example, you might discover that your outside lights take approximately 3 times the energy of the inside living room lamp. After a short time you will develop some instinct for the electrical usage--just like you might know about how much the bananas in the store are going to cost before you look at the price. This awareness will help the users of the system to conserve energy.

Watch those 24 hour per day "ghost" loads: The total electrical usage (amp-hours) of an appliance is the quantity of electricity used (amps) times the time that it is on (hours). Energy conservation awareness includes knowing about the electrical loads that may take little power, but are on all the time--sometimes called “phantom” or "ghost" loads. These can take a lot of energy in a day. For example, a remote controlled TV usually takes some power when "off"--to keep the remote control circuitry active. Answering machines or chargers (like electric toothbrush, or other small tool chargers) that use those wall plug cubes usually take a little power all the time. The inverter that converts your battery power to ac power will take a small amount of power when it has minimum loads on it. Use the TriMetric to monitor the current (in amps) with all lights and regular appliances "off". Multiply by 24 (hours) to find out the "amp-hours" per day. Compare this number with your total amp-hour production in a day to see what percentage this is. If you discover it is too high you may want to switch them completely off or take other measures to decrease their consumption.

Check that all appliances are really off when going to bed at the end of the day, or when leaving the house. Glance at the "amps" display to see that it is at its expected minimum level.

C2. Using the monitor to properly care for batteries.

Most owners of energy systems use lead acid batteries--and this section assumes you are using lead-acid batteries. If you have another type of battery chemistry, check with a dealer or other person knowledgeable about this.

Battery philosophy: Energy systems and credit cards--There seem to be two opposite "styles" of using a credit card. Some people use their credit cards frequently, but pay off the balance each month--and rarely if ever go even near their credit limit. Then there are other, opposite types of people that carry a large balance from month-to-month--and only stop spending when they've exceeded their credit limit. They pay the minimum amount necessary and go to the next month. The interesting thing is that *it doesn't cost any more in the long run to pay the balance off each month*--in fact even less, because interest is being saved. It is similar with renewable energy systems. Lead-acid battery systems last longer if they stay relatively full rather than relatively empty--so keeping them always at low charge will reduce battery life--rather like paying extra interest on your investment. If you keep them relatively full they will last longer. Since all the energy used must be generated at some time, within limits it makes sense to keep them closer to the full side rather than empty. However one *can* go overboard the other way, too, and insist on having a solar array that will fully charge them every day before noon. Batteries (unlike the bank) are limited in their ability to store, so although it's good for their health to overcharge them slightly, excessive zeal to insure that the batteries are always full could make the system more costly than necessary by providing more generating capacity than really required, and also make the system less efficient--because if the system is already full it would not be able to store an extra energy windfall if a temporary period of lower usage, or higher energy generation becomes available.

Battery safety.

Batteries can be dangerous! *They should always be inaccessible to children. If a metal tool or other conductor shorts across battery terminals it can **instantly** get very hot and cause a fire or burns. Remove metal rings while working with batteries, which if they short across battery terminals will cause severe burns. Although rare, batteries **can** explode from hydrogen and oxygen gas inside the batteries and spray acid everywhere. Or when adding water some acid could accidentally splash and hit eyes. Use safety goggles to protect eyes from this possibility. Purchase a pair of goggles and store them in the vicinity of the batteries so they are handy to use when working around them.*

Lead-acid Battery Rule 1: Usually keep them above 50% state of charge. The general idea is to keep your batteries toward the top of their charge rather than toward the bottom. And if you need to use the generator to do this, don't wait until they are all the way to the bottom before turning on the generator. Use the "% Battery Full" or "amp-hour from full" display to keep yourself informed about the state-of-charge of the batteries. If you use the "amp-hour from full" display you'll need to know what your battery capacity is, in amp-hours. Once you become used to your system and your normal electrical usage you will only occasionally need to refer to the meter.

This rule should encourage you *not* to always wait until the inverter cuts off your power because the system voltage is too low--and then charge.

Lead-acid Battery rule 2: If they do become discharged, recharge as soon as possible. If you do slip below 50% state of charge it isn't going to hurt very much if you get them up to full charge again soon. If they become completely discharged, don't allow them to remain in this state for long--certainly not over 24 hours. When the batteries are where they should normally be--above 50% state of charge-- the battery "volts" is not usually a reliable indicator of "state-of-charge". However, when the batteries are getting way too low in charge, the "volts" reading is a good indicator tell you that this is happening. The "Battery reminders" function will also flash a warning "b.LO" if the battery voltage goes below the desired "minimum battery voltage", which you can choose and program in to the TriMetric. **When battery voltage goes below 11.0-11.2 (12 volt systems) or (22.0-22.4 in 24 volt systems) volts the batteries are becoming more discharged than they normally should.** By this time you should have been prewarned before by the "amp-hour" reading getting below 50% charge point. And if not, the battery capacity may be getting lower than expected due to age or past mistreatment--or they simply may be colder than normal. The "volts" reading is the authoritative indicator that the battery is at or near discharge --for example if the battery system has lost capacity because they are old, or have suffered abuse--or perhaps because they are colder than normal resulting in temporary lower capacity (until rewarmed again). If you discover that the voltage has become excessively low when the "amp-hour" reading would indicate that some energy is left, you may want to recalibrate your battery capacity estimate for the future, or check your batteries or the connections to see if something is wrong. Incidentally, the "minimum volts" data function of the TriMetric, (the d. 6 function), can be used to check how low the voltage has gone while you are away, or during some period in which you do not wish to constantly monitor the "volts" reading on the meter.

Lead-acid Battery Rule 3: Fully charge every week or so. Every week (or more often) you should charge the batteries sufficiently for the TriMetric to reach the "charged" setpoint, which is both good for the batteries, and it will also resynchronize the TriMetric "%Battery full" (and "amp-hours from full" display) with the batteries. You can observe how long ago the batteries were fully charged by examining the "days since charged" display. In addition, as described in the TriMetric instructions, you may program the battery reminders function to remind you to recharge the batteries if they have not reached "charged" in 5 days, or any other number of days that you choose. -

If you sometimes use a generator to recharge your battieries, the section below '**Using the TriMetric to minimize generator usage"** will be useful.

Lead-acid Battery Rule 4: If you have "flooded" lead acid batteries, equalize every 1-2 months

"Equalization" is a term often given to describe the process of occasionally over charging the batteries. "Over charging" is not necessarily synonymous with "abuse"--it just means to put in more energy than the batteries can hold.

One purpose of "equalization"--from which the name is derived--is to cause all the individual series cells in the battery to become equally charged. However it serves other functions as well. A second function is to do a very complete charge of the battery. When the battery is charged enough for the TriMetric to sense that the batteries are "charged", the battery usually is not yet 100% charged, although it is generally over 85% charged. If some of the battery reaction products remain in their uncharged state too long they undergo changes that make it very difficult to reconvert them back to their "charged" state, thus making the battery progressively more difficult to fully charge. This is referred to as "sulfation" of the battery, which causes eventual loss of capacity. Another purpose of equalization is to mix up the electrolyte in the battery, which happens because of the gas bubbles that are produced when overcharging.

Of course, just like overflowing a gas tank, equalization does waste a little energy, but if you don't occasionally equalize, especially if your batteries are often not fully charged, the batteries can gradually lose capacity.

Some charging systems have an automatic equalize function--others have a manual switch. Follow the procedure recommended by your installer, dealer or battery manufacturer. In some cases chargers do equalization automatically, and no operator attention is required. In other cases it involves changing a switch position on the controller to "equalize" for a specified amount of time, or for a recommended number of amp-hours overcharge. More frequently, however, rather than keeping track of the number of amp-hours overcharge, a manufacturer may recommend that the voltage be raised to a fairly high voltage for a set period of time, for example the Trojan battery company recommends 15.5V for 4 hours for a 12V battery system, performed every month or two, with charging at a rate of C☼20 or less, where C=capacity of the battery system, in amp-hours. **After equalizing is usually recommended as the best time to check water levels** and add additional amounts of distilled water if necessary. Equalization generally causes the electrolyte level to rise slightly--so adding at this time minimizes the danger of overfilling. **The TriMetric Model 2020 "battery reminders" feature** is useful to remind you when to equalize. This is just a timer which you reset to "0" when you equalize the batteries. After, for example, 45 days (which number you may program into the TriMetric) the "battery reminders" light will flash and "Ch.E" will flash in the display every 12 seconds to remind you to equalize again. After you equalize batteries you can reset the "Days since equalized" function by pushing the "reset" button (while "days since equalized" is displayed) until the display flashes 3 times. This turns off the reminder, which will reappear to remind you to equalize again after 45 more days have elapsed.

Other miscellaneous battery maintenance items (not related to meter measurements):

Periodically check and maintain water level of "wet cell" batteries. Every 2-3 months check the battery water levels. They should not be allowed to fall below the top level of the plates--and should be filled up to the marker--often the bottom of a cylindrical hole covered by the battery cap. Add pure distilled water only--and as mentioned, the best time is just after equalizing the batteries.

Keep batteries at correct temperature range. Ideal temperature is 60-80° F. (15-25° C.) At higher temperatures batteries suffer reduced life. At lower temperatures they have reduced capacity, however even at 32° F. (0° C) they have about 70% capacity, although they don't absorb charging current as readily so it takes longer to charge them fully. If batteries sit below 20° F they can freeze if in a low state of charge, which will destroy the battery. If they are kept reasonably well charged (75% or greater) however, they won't freeze even at minus 40° F.

Occasionally check connections. Battery connections can sometimes develop excessive resistance. This will cause apparent loss of capacity, and possibly improper charging of some batteries in a parallel group, which can cause battery damage. (A section in Part 2 of this guide --to be written-- will describe an easy and reliable way to do this using a hand digital voltmeter by measuring the voltage drop across connections while discharging the battery.)

Keep tops reasonably clean. Battery tops, being horizontal surfaces, sometimes collect quite a bit of dirt. Occasionally clean these off to reduce possibly of stray current leakage.

3. Using the TriMetric to minimize generator usage.

When it is necessary to use the generator to supplement energy input to fully charge the batteries, it is usually desirable to reduce the generator time for several reasons--including cost, air and noise pollution caused by the generator. Here is a good strategy for doing recharging to reduce generator time and also increase battery life. It is based on two important facts:

Fact 1: The generator charging rate (in amps) is greater--and often much greater than renewable sources such as solar or wind. Generally the renewable energy resource is available for a long period, but at a lower charging rate (amps).

Fact 2: Batteries are willing to absorb energy the fastest rate when they are at *lowest* state-of-charge. As they become more fully charged it takes more *time* to absorb the energy properly. If you try to charge too fast at the end of charge, it just drives the voltage up without actually charging the battery any faster. This can waste energy and overheat the batteries without accomplishing real charging.

The conclusion from these facts is that for greatest efficiency the generator should be used to charge batteries when batteries are at a low state of charge and the solar array should be used for doing the charging when the batteries are more fully charged.

One *wrong* way use the generator is to wait until the solar array gets the batteries as close to "charged" as possible, then when you see you're not going to make it with the solar array, turn on generator to get the rest of the way. It is more efficient to use the generator when batteries are at *lowest* "% battery full" or "amp-hour from full" point--for example in the later part of the evening, or early morning before significant sun if solar is expected in the daytime.

Strategy for using the monitor to know when and how long to run generator. For minimum generator usage, estimate how many amp-hours your solar array (or other source) will be able to charge the next day. Then, when the batteries are at a low point, such as later in the evening, or early morning an hour or more before significant sun, charge them with the generator until the amp-hours on the TriMetric shows a value smaller than the amount your solar array will be able to produce the next day. You can get double benefit if you choose a generator run time when you are using higher than normal loads--so while the generator is charging, it can also supply power to these loads rather than using battery power that will later need to be replaced by further generator run time. **There are two**

benefits to this method: you will run the generator quite a bit less this way, and it will give your batteries a better charge because they spend more time at low charging current at the end.

Example: if you know you can charge 100 amp-hours per (sunny) day with the solar array, (and you expect sun tomorrow), if the "amp-hour" number on the TriMetric is down to -130 amp-hours, turn on the generator to charge until you are down to -80 when the solar modules start producing. The solar modules the next day should fully charge the batteries, which can be confirmed later that day by checking the "days since recharged" display. If you can also manage to schedule the generator while you are using heavier than average loads, further generator time will be avoided because not as much battery recharge will need to take place.

Optional information about charging rate: One traditional rule for lead acid batteries is the "ampere-hour rule": that a lead acid battery can absorb amps at a rate (in amps) equal to number of amp-hours away from full charge. In other words, the number of *amps* (while charging) shown on the TriMetric should be equal or less than the number of *amp-hours* shown on the TriMetric. The implication of this rule is that although the current can start out very high at low state of charge, (when the amp-hour number is a large negative value) it must gradually taper down to 0 at the end of charge to spend more time at the end. This rule is probably most applicable to "auto" batteries which are designed for high currents--so for the type of "deep-cycle" batteries used in renewable energy systems it is probably best to limit charging current (in amps) to 50% or less of the value of "amp-hours" left in the battery bank. **Example**: if the meter shows -100 amp-hours, the batteries can absorb 50% of 100, or 50 amps of charging current at that time. As charging continues, the charging rate must decrease for the batteries to fully absorb the charging current.