STIKOPEDIA

SUPERIOR TECHNOLOGY INTEGRATION KNOWLEDGE

SOLAR STIK™

LEGAL NOTICE

Solar Stik®, Inc.
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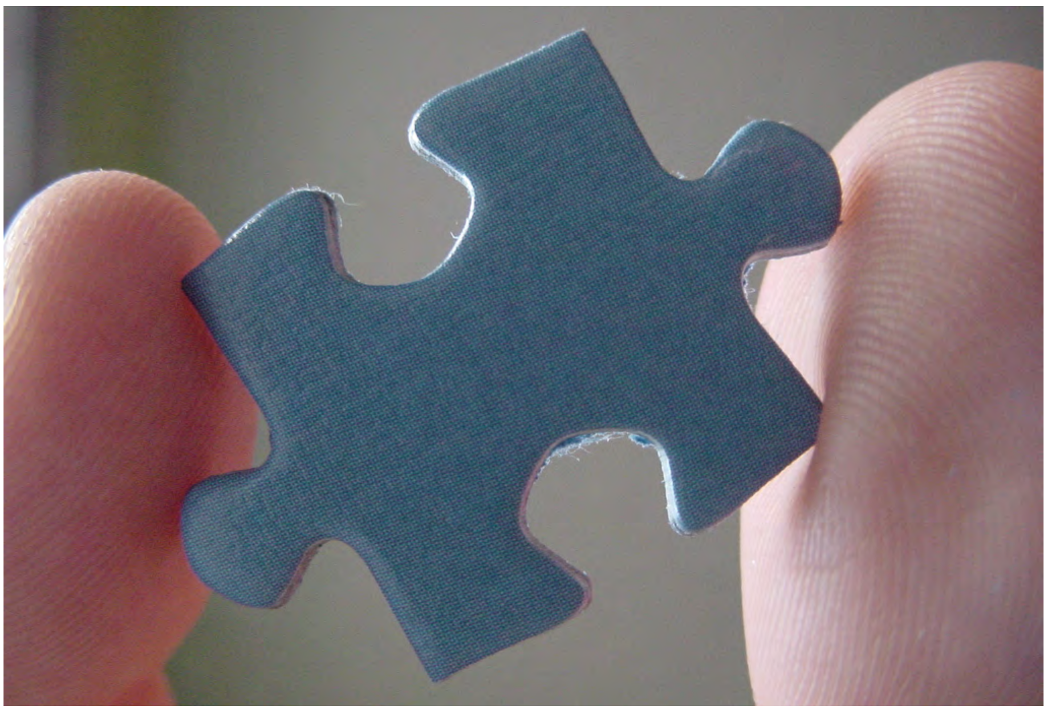
"If a man did a job so well that no other man could find fault with it, nothing would ever get done."

-Chuck Mitrision, 2005

Preface

Stikopedia is designed to be a compilation of everything you would ever want to know about portable energy systems, including the philosophy and mechanics of high-efficiency circuits, as well as the individual technologies employed in them. Portable power can be imagined as a picture puzzle, where various essential pieces come together to form a whole. However, if the operator doesn't know what the final picture will look like, the difficulty of assembling the puzzle is amplified significantly.

Stikopedia is designed to help the operator identify the picture, and thus understand how the various pieces fit together. The picture on the puzzle is always the same: a complete, functioning electrical circuit with all of the pieces operating in harmony with one another. The only differences between any puzzles are the shapes and quantity of the pieces.



As a training manual, Stikopedia corresponds to distinct modules within our training curriculum. It greatly enhances our other training materials as well as presentations from our trained instructors during half-day crash courses or week-long field training exercise.

Stikopedia is also intended to be a stand-alone guide for anyone who wants to learn more about portable high-efficiency, portable power and the Solar Stik System. This means we're writing for everyone from the casual reader with an interest in portable power for a personal need, to the experienced electrical engineer learning a new application in his or her field. Readers can select the modules that interest them. For example, an engineer could probably skip our introduction to basic electricity, whereas a casual reader is probably less interested in the specific product schematics and appendices. But we do suggest you be familiar with the overall flow of Stikopedia, because although an individual module may not hold your interest, it is important to understand how interdependent our company philosophy, system architecture, and component design truly are.

Furthermore, there are several ideas that resonate throughout the curriculum, although sometimes in varying formats and perspectives. These repeated exposures help reinforce basic principles and ideas that are important for the reader to understand.

For example, “Efficiency” can mean different things, depending on the technology it is associated with. The formula for determining **efficiency** is strategically referred to throughout the entire Stikopedia document, with each reference in a different context.

$$\frac{\text{THE USEFUL WORK PERFORMED}}{\text{TOTAL ENERGY EXPENDED IN ACCOMPLISHING THE TASK}} = \textit{EFFICIENCY}$$

Repetitive exposure to this Efficiency Formula with different associations of application demonstrates to the reader that “efficiency” is an important factor at every facet of a “High-Efficiency Electrical Circuit” and not just at one point in the system.

Summarily, our goal is for the reader to be able to look at **all** technologies used in electrical circuits through the prism of their efficiencies, and not just their application. We have designed Stikopedia to answer questions we ourselves would ask if we approached the Solar Stik System for the first time. We try to keep the jargon and overly technical language to a minimum, and to include a surplus of information. We recognize there is no perfect manual for any product or company, so Stikopedia is always evolving as we at Solar Stik strive to create an entirely new paradigm and multitude of products and for an exciting young field!

Technology is constantly evolving, so the information presented in this document may not reflect the absolute latest advances. Please check the Solar Stik website frequently for updates to the Stikopedia document.

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SOLAR STIK®

STIKOPEDIA

MODULE ONE

The Primer: "The Picture on the Puzzle"

WHAT IS **PORTABLE POWER?**

Defining Portable Power

What comes to mind when you think of portable power?

Obviously, traditional power supply systems–"grid" energy--require a physical connection to the power source. Generally this implies many conduits (such as electric lines) that branch out from a centralized source (such as a coal plant) where the power is produced.

This centralized system allows for efficiency and steady supply, but is necessarily limited by the placement of its conduits; that is, if the infrastructure is not in place, power cannot be served.

In fast-moving or remote applications, portable power is preferred over traditional sources, because they bypass the infrastructure requirement.

Over the last few decades, mobile power applications have seen explosive growth. However, choices in power sources have remained fairly constant–the portable, fuel-driven generator is still the primary mechanism or tool used in portable power applications.

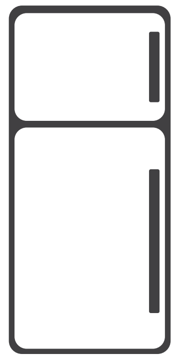
Challenges facing the traditional paradigm are what have led to a new age in alternative portable power solutions, including the Solar Stik System. There is a seismic shift toward hybrid, renewable, and other battery-operated portable power products, and they are fast becoming part of the mainstream.

In an age where technology evolves at such a rapid rate, the options available to the operator are increasing both in number and effectiveness every year.

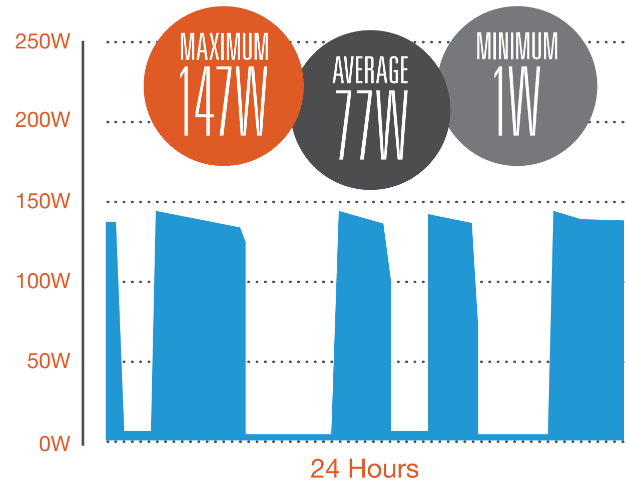
The Dynamic Nature of Electricity

In any electrical circuit, electricity flows dynamically. This means that electricity flow through the circuit will vary in accordance with both the appliance requirements (loads that use power) and the power generators (devices that produce power).

For example, communication devices, medical equipment, lighting, and refrigerators all consume energy in a dynamic fashion: refrigerators only consume power when the thermostat calls for colder temperatures; communication radios consume more power when transmitting than when simply listening. Additionally, generator power production can fluctuate widely based on factors such as temperature, altitude, and fuel.

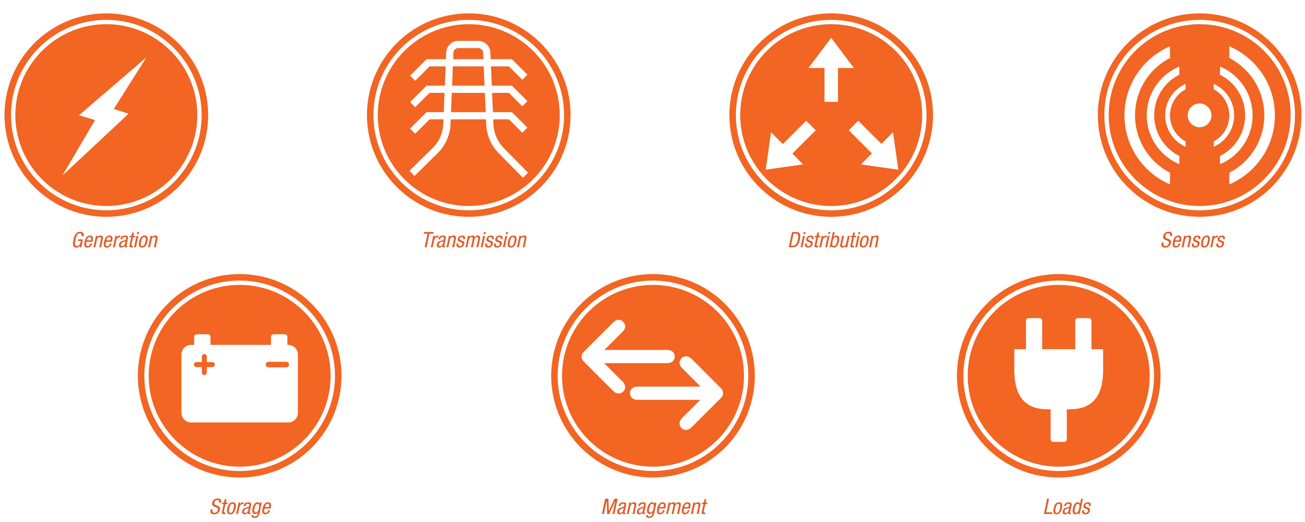


Refrigerator Cooling Cycle



Rethinking the Traditional Portable Power Model

A typical portable power model can be characterized as closed circuit, or micro-grid, and usually includes at least two of the following categories of components.



Portable power systems can range in complexity depending on the technologies involved, but one signature of all portable power systems is that they have the ability to operate independently, in the absence of traditional sources such as grid- or utility-produced power.

The Learning Curve of Independence

The primary reason for using a hybrid, battery, or other high-efficiency portable power model is simple: such models provide the operator with maximum independence through a solution tailored to their specific needs. It may sound complex, but it is simply the proper marriage of technology and application!

In that vein, the more an operator understands how to effectively integrate and use an electrical circuit based on high-efficiency principles, the more autonomy the operator can achieve.

The key is to understand how to identify the best capabilities for a particular application.

The Power Budget

In many light-duty applications requiring less than 3,000 watts daily, renewable generators can often completely replace the light-duty gasoline generators that have long dominated the portable power landscape.

Generators differ by their operating efficiency, the amount of power they produce, and how they generate power

Renewable

A renewable generator, such as a solar (photovoltaic or PV) panel, harvests power from the environment, storing it in batteries. Connected appliances draw from this stored power as needed.

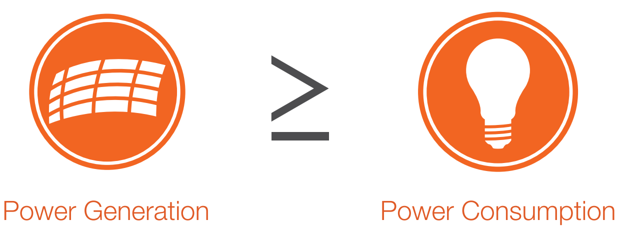
Fuel

A fuel-driven generator must run continuously in order to supply power to connected appliances, even if the power required is minimal or intermittent.

All portable power generators—whether driven by traditional fuel, solar or wind energy, or alternative fuels—have their limitations. Because of this, operators should establish a power budget in order to select technologies that are appropriate for their given applications and available resources. Establishing a budget is the first step in ensuring that the solution is effective and provides as much autonomy as possible for the operator.

When establishing a budget, the operator must know the power requirements of the application before the portable power system can be configured properly.

Properly establishing a budget sufficient for the task is important, because one ironclad rule of power generation is that power generated in the circuit must be greater than or equal to the power that will be consumed in the circuit.



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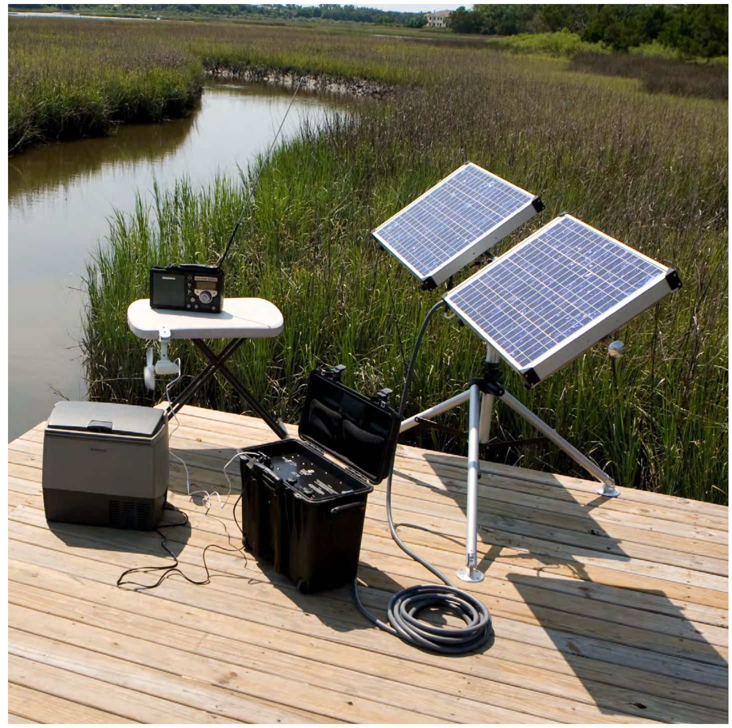
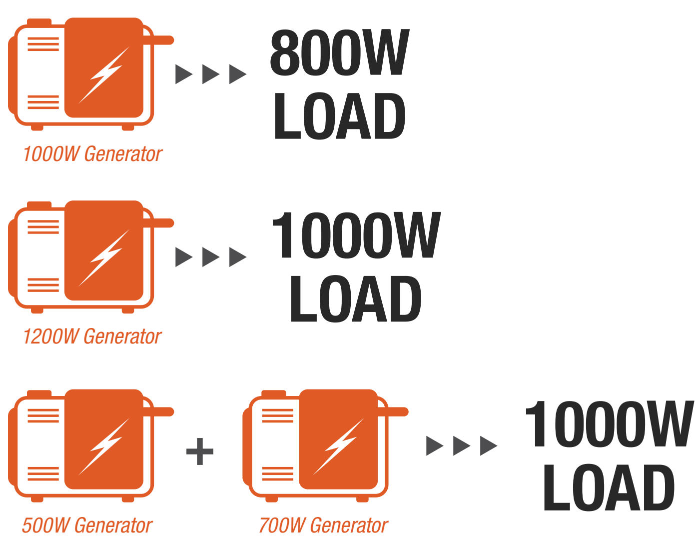


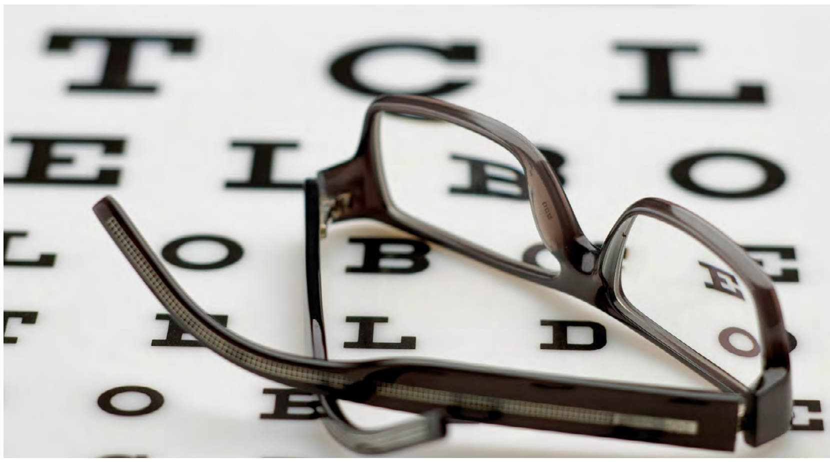
For example, if an operator has an application (load) that requires only 1000 watts (1 kW), then the operator should be able to determine the best integration of technologies that will most efficiently provide uninterrupted power for the application.



A Game of Averages

Despite the highly refined mathematical methods and instrumentation we have today, it is still very difficult to calculate exact values for the power that will be generated and consumed in a portable electrical circuit.

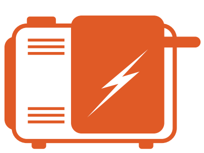
Conversely, it is fairly simple to determine exactly how much power was generated and consumed in a circuit at the end of a period of time.



"Hindsight is always 20/20"

For example, many power generators today are rated, by their respective manufacturers, according to the maximum possible power output:

- A 3000-watt fuel-driven generator has a maximum power output of 3000 watts.
- A 400-watt wind generator has a maximum power output of 400 watts.
- A 62-watt solar panel has a maximum power output of 62 watts.



3000 W Fuel Generator

3000 watts Maximum

400 W Wind Generator

400 watts Maximum

62 W Solar Panel

62 watts Maximum

These ratings are often generated in a laboratory environment and do not take into account the de-rating (power degradation) often caused by operation in hot environments, type of fuel used, diminished sunlight, effect of light winds, altitude, geographic location, or a combination of factors, as is usually the case.

Similar effects lead to de-rating at the load, often for the same reasons.

In the end, it is highly recommended that the operator look at the total amount of power that flows through a closed electrical circuit over time as a game of averages.

Traditional Fuel-driven Generators

Users often choose fuel-driven generators for convenience. Powering appliances with a fuel generator is simple: just turn it on, plug in appliances, and refuel as needed.

Fuel-driven generators are effective for temporary power production; however, they are poorly suited for long-term power requirements because the cost to operate a fuel generator is dependent primarily on its runtime.

Many fuel generators are built to run at a single speed, and they are often inflexible with regard to power output and fuel consumption.

When an appliance requires less than the rated output of a fuel-driven generator, the generator wastes fuel, as it will continue to convert the energy of the fuel into usable electricity, even if it that electricity is not being used.

"When an appliance requires less than the rated output of a fuel-driven generator, the generator wastes fuel, as it will continue to convert the energy of the fuel into usable electricity, even if it that energy is not being used."

Operating challenges are compounded if the generator is used in a remote location, after a disaster, or for long-term power applications.

Other challenges include:

- Logistics such as fuel transport and storage
- Required interval maintenance
- Replacement of worn parts

Because of these challenges, the overall costs of operating a portable fuel generator extend far beyond the initial purchase price.

Additionally, most manufacturers only guarantee fuel generators for one to two years, because of the varying runtimes they may be subjected to and the subsequent de-rating of the generator.

"Cost" of Fuel in the Portable Power Market

The cost of fuel cannot be calculated in dollars per gallon alone. Fuel supply, storage, transport, and equipment maintenance require consideration to calculate the actual cost of using a portable fuel generator.

Alternative Fuels

In the portable power market, using alternative fuels in place of traditional fuels will have little benefit or impact on the overall cost of operation. The real cost of using fuel is in the logistics of supporting fuel-based, portable power generation, and using alternative fuels does not reduce these costs.

Depending on the alternative fuel technology used, the cost may actually increase in the early-adoption phase, as the infrastructure for supplying alternative fuels is generally inadequate when compared to the existing infrastructure that supports the use of traditional fuel.

Portable power technologies that use alternative fuels, such as fuel cells, require refueling just like a traditional gas generator. Because of this, the cost of supplying fuel to the generator is not reduced, but merely shifts from one technology to the other.

Engine Efficiency of a Fuel-driven Generator

Using a gallon of diesel fuel to rotate a generator to produce electricty includes many points of loss. Energy is used to overcome friction inside the engine (cylinder walls, crank, camshaft, and main bearings) as well as friction within the pumps, drive shaft, and loads on the generator. Heat is also a form of energy, and is lost through the exhaust pipe, the engine block, and the radiator.

Also known as motor efficiency, engine efficiency is the relationship between the total energy contained in the fuel and the amount of energy produced that is actually used to perform useful work.

$$\frac{\text{THE USEFUL WORK PERFORMED}}{\text{TOTAL ENERGY EXPENDED IN ACCOMPLISHING THE TASK}} = \textit{EFFICIENCY}$$

Case study: MEP-831A

Consider the efficiency of the MEP-831A, a 3-kW fuel-driven generator. Keep in mind the conversions below:

1 gal. DIESEL = 129,500 BRITISH THERMAL UNITS (BTU) = 37,952 Wh (38 kW)

3kW Diesel Generator

$$\frac{\textbf{3-HOUR RUNTIME}}{\textbf{1 gal DIESEL}} = \frac{\text{9000 Wh PRODUCED}}{\text{37,952 Wh CONSUMED}} = 24\%$$

24% EFFICIENCY
(ASSUMES FULL 3 kW LOAD)

If the generator load is less than 100 percent, multiply the actual percentage of generator output by the maximum efficiency (24 percent). And because most traditional fuel generators operate under less than 100 percent efficiency, that number is generally significantly lower.

$$\frac{\textbf{3000 Wh USED BY LOAD}}{\textbf{9000 Wh PRODUCED}} = 0.333 \times 24\% = 8\%$$

8% EFFICIENCY

Advantages of Fuel-driven Generators

It is important to note also that as of today, fuel-powered generators still have an advantage over renewable generators. Liquid fuel generators tend to be the most prevalent of portable power solutions because the energy density of liquid fuel is still the highest of all fuel options–outpacing solar, wind, and other renewable options--and because liquid fuel already benefits from having the infrastructure needed to bring it to an end user. However, these advantages are diminished when system efficiency and logistics are taken into account.

Additionally, fuel-powered generators can usually operate without regard for the surrounding environmental conditions. The limiting factors instead are usually the availability of fuel and the need for ongoing maintenance. However, restricting the generator to a single function, such as charging the batteries of a hybrid power system, will reduce run time and cost, ensuring that any energy created from burning fuel is stored as potential energy in the battery and delegated to the loads only as required.

Advantages of Renewable Generators

The advantage of using renewable power in any electrical circuit is easy to understand. The ability to harvest “free power” from natural sources is not only responsible, it also has positive less tangible benefits, such as quiet operation, small footprints, ease of use, low maintenance, and autonomy for the user because it reduces dependence on traditional means of generating power.

Advantages of a Primary Battery in a Closed Loop Circuit

Using batteries as the primary conduit for all power that flows in portable electrical circuits provides the greatest benefit of any power model for three reasons.

1. It immediately increases the efficiency of the entire circuit.
2. It opens the architecture of the circuit to allow for the use of multiple power sources (including traditional and renewable power sources) and technologies that directly support the application.
3. It allows for multiple levels of control to be implemented, allowing the operator to establish operation protocols based on specific requirements for the application.

Batteries in an electrical circuit act as a buffer between power generation, management, and the loads.

In a high-efficiency electrical circuit, all functions revolve around the battery, and control over the entire circuit can be exercised using a single value--the battery state of charge (SOC).

Logical Solution: A Battery-based Hybrid System, or Micro-grid

In a battery-based hybrid system, renewable technologies such as solar and wind act as primary power generators, while traditional fuel generators act as secondary, or backup, power sources. All power generated from these sources directly supports the battery bank. In turn, the battery bank supplies exactly the amount of energy required to provide continuity of operations in a given application. Power only flows through the entire circuit as is necessary.

Using a battery bank to store and provide power ensures that any fuel energy expended to generate power (such as diesel) is used to either support the load directly or to recharge the battery bank. Hybrid systems allow manipulation of the circuit while it is active. Should the conditions change, the open modular architecture allows the user to modify the system accordingly.

A hybrid system mitigates the risk of dependency on a single power source, while dramatically increasing operating efficiency. Additionally, the open architecture of the hybrid configuration allows operators to tailor the system capabilities to directly support current and future applications. The high degree of electrical circuit reliability, due to built-in redundancy, is important for critical operations where uninterrupted power is required.

Selecting Power Sources for a Micro-grid

Every portable power system faces limitations that can prohibit full dependency on a sole power source. Fuel generators require fuel to operate, but the fuel may not always be available; renewable generators, such as solar and wind, rely on environments that can be uncooperative.

Given these limitations, systems with a single power source may not always be able to satisfy power demands. The logical step in mitigating dependency on only one power solution is using a micro-grid configuration that draws from more than one type of power source.

When using a battery to supply a micro-grid, the operator can choose from multiple power-generation options to support the battery.

Considerations for Choosing a Power Generation Technology

Sunlight environments (desert and ocean)

High wind environments (mountaintops and plains)

High water currents (streams and rivers)

Grid AC power, such as utilities (intermittent or constant)

Proximity to fuel resupply (fuel depots and supply lines)

Examples of Power Source Selection

If an operator at a forward operating base (FOB) in Djibouti has access to significant sunlight on a daily basis, he should use as much solar generation as possible while maintaining a secondary power source, such as a diesel generator, to ensure continued operation.

If a communications technician works on top of a mountain in Afghanistan, a wind generator would likely provide her with most of the power necessary to operate the radio.

If a provincial reconstruction team in Iraq deploys to a remote region with a source of flowing water, the team should employ waterpower generation.

Examples of Power Source Selection - Striking a Balance

It is critical to have a balance between all components in a closed-loop electrical system. Striking this balance means knowing the following:

Amount of Power Consumption — *Amount of Power Generation* — *Amount of Energy Storage*

The yields of a balanced system are especially visible in situations where traditional portable power generators are often used:

- Reduced costs
- Reduced logistical burdens
- Increased autonomy

The more one understands how to effectively design, integrate, and use a circuit based on stored-energy principles, the more autonomy one can achieve.

"Open Architecture" means "Modularity"

The architecture of a properly-configured portable micro-grid should allow for the addition, replacement, or removal of system components as necessary for upgrades, repairs, or when changes in capabilities are required.

Open architecture allows two types of integration:

1. **Field integration**
   Multiple technologies may already be in use or available to the operator.

2. **Planned integration**
   The operator designs a system to meet the needs of a specific application before deploying the desired equipment.

A circuit that uses modular architecture provides:

- Tailoring of system capabilities for a specific mission or load profile
- Reduced logistics, with an ability to deploy exactly what is needed
- Increased safety due to polarized connections, circuit protections, and other safety protocols built in to the circuits, allowing setup and operation with only minimal training required
- Easy troubleshooting that allows diagnosis of individual components instead of micro-level parts
- Continuity of operations; if one modular component in the circuit fails, it can easily be replaced or bypassed without losing the rest of the circuit functions

Batteries and Generators - Natural Complements

Batteries and fuel-driven generators are natural complements to one another. If a fuel-driven generator is being used in a portable power circuit as the primary method of generation, one of the following two conditions will likely apply:

The generator is not operating at its maximum rated power output.	*The generator is operating at maximum rated power output.*
• The installation of a battery relegates a fuel-driven generator to a support role (recharging) for a battery bank, allowing it to be used only when the battery SOC is low (reducing run time, maintenance, and fuel consumption).	• The installation of a battery provides power stability and security (continuity of operations) in the event of a generator shutdown. The batteries serve as an Uninterruptible Power Supply (UPS), bridging the gap when generators are shut down due to failure, maintenance, refueling, or upgrade.

Selecting a Fuel-driven Generator for a Hybrid Electrical Circuit

There is a rule to remember when selecting a traditional fuel-driven generator for use in a hybrid system:

The generator should be able to supply all of the power necessary for the load in the event that it becomes the primary source of power for the circuit.

The fuel type, brand, and features of the generator are negotiable. However, the minimum power output rating is a critical feature when integrating into a circuit with minimum power requirements.

For example, if the circuit is being designed to support a cumulative or intermittent load of 5,000 Watts, then the minimum generator capability should be 5,000 watts.

Harnessing and Scavenging Power – Get Creative!

Have you ever sat on the floor in an airport so you could be close to a power outlet?

We've all seen weary travelers sitting on the floor next to the garbage cans, or in the aisle seeking an outlet to plug in and recharge their personal electronic devices. As new technologies continue to permeate our lives, we are becoming more dependent on power sources to keep them operating.

In a hybrid system with open architecture, the same creative principles can apply. Operators should always be on the lookout for ways to scavenge power from the environment, including readily available sources such as:

Vehicles
All vehicles have electrical systems, and as such, are great sources of power when available.

Fuel Generator
If a generator of any type is operating, a user can often siphon off some power while it is convenient to do so.

Environmental
As seen in the "renewable energy" industry, solar, wind, and hydroelectric power are all potential sources of energy.

Batteries
Disposable batteries often have power left in them that can be scavenged for use into the primary battery of a hybrid system.

Other sources
Energy can be found almost anywhere. Be creative and resourceful.

"A Watt is a Watt is a Watt"

It is important to remember that within a power circuit, a Watt is a Watt is a Watt.

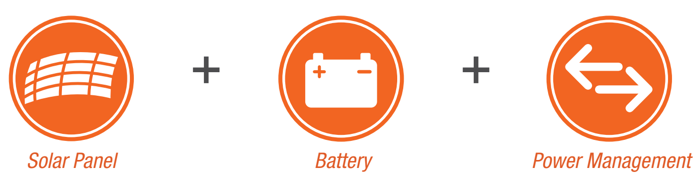
- Watts never change in a circuit.
- Watts generated must be greater than watts consumed.
- Where the watts come from is irrelevant to the load. All that matters is that enough watts are brought into the circuit to keep the appliances operating. The source of the generated Watts is decided based on geographic location and available resources.

Industry Standards and Practices

New power technologies are being introduced nearly every year.

It is not possible for one company to produce all of the technologies brought to the marketplace. Many of these technologies are multi-functional, and as such they are sold as an "unfinished product"–meaning that they do not function alone as a system, but instead must be assembled with other such parts to form a working system.

For example, a solar panel is often unusable by itself, but if integrated into a system that includes a battery and a power management device it can serve a vital role as a power generator within a system.



Companies (such as Solar Stik) integrate emerging technologies into working systems by incorporating various components into a "manufactured" turn-key solution ready for use in portable power applications.

It is incumbent on the operator to recognize how these and other "unfinished" components will fit into their individual portable power paradigm, while acknowledging the limits and benefits of the pieces of the puzzle for proper fit and function into the prospective circuit based on both the spectrum of power and the application itself.

Unfortunately, there are currently no connection standards between many of these technologies, so industry partners, and often the operators themselves, must endeavor to bridge the gap.

Return on investment (ROI)

For most applications requiring portable power, a circuit that employs renewable power can reduce dependence on biofuel, gasoline, and fuel cells. This alleviates the logistical cost associated with traditional portable power generation. Because of this, a high-efficiency system often pays for itself within a short period of time.

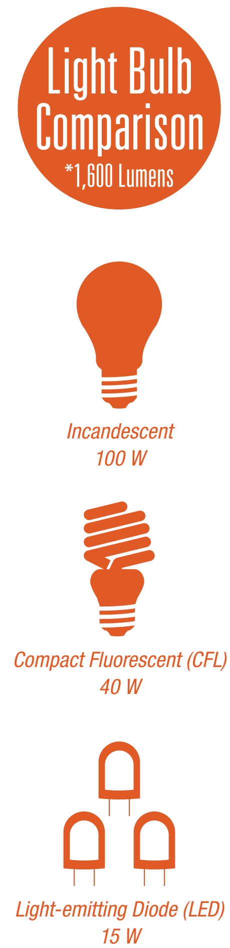
APPLIANCES AND **POWER SOURCES**

Increased Efficiency in Appliances

Technology is evolving rapidly, and appliances (loads) are becoming increasingly efficient. Electrical appliances manufactured only five years ago consume greater amounts of power than their present-day counterparts when performing the same tasks.

Lighting is a good example of this progression. Fifteen-Watt light-emitting diode (LED) and 40 W compact fluorescent (CFL) technologies produce the same amount of visible light, measured in lumens, as does a 100 W incandescent bulb—yet these newer, more efficient technologies consume only a fraction of the power relative to the incandescent bulb.

This increase in efficiency is a growing trend in appliances, from lighting to refrigeration, electronics, communications, medical gear, and more.



Benefits of a Highly Efficient Appliance

Appliance efficiency is also known as load efficiency. As appliances consume less power, power source requirements also change. When designing a portable electrical system, purchasing highly efficient components can provide many benefits.

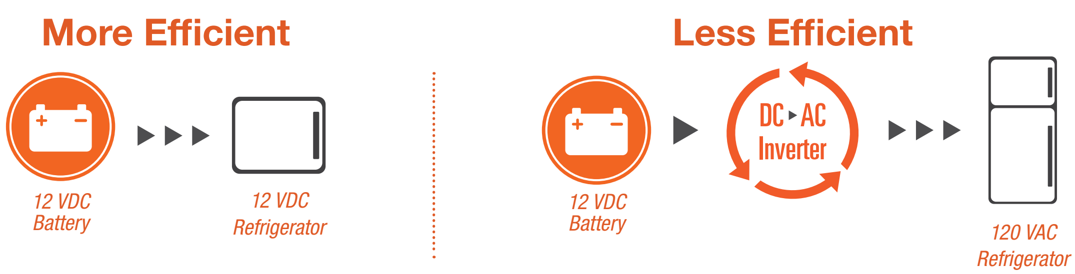
With portable power systems, a smaller load means more options for power sources, or less dependence on traditional ones.

For grid or fuel-generator supplied power systems, less power consumed results in lower operating costs for appliances.

Appliance Compatibility

Appliance loads can often be matched to the electrical characteristics of the circuit. This will increase the system's overall efficiency by allowing direct connection to the circuit without the need for additional power management devices to aid in the function.

For example, a 12-volt direct current (DC) electrical circuit powered by a 12 V battery can directly support a refrigerator that also operates at 12 VDC. This setup will transfer power through the circuit more efficiently than if the refrigerator requires 120 V alternating current (AC) power. In the latter example, an inverter would be required.



Less is More

The fewer management components used in a system, the more efficiently it will operate.

For example, components such as inverters, converters, or similar devices used in a circuit to "adapt" appliances for use in a particular electrical circuit themselves require power to operate, and thus the total power required to operate the appliance is increased.

Identifying a DC Appliance

Identifying a DC-powered appliance (load) is very easy. There are two basic criteria

- Does it have a battery in it (disposable or rechargeable)?
- Can it run directly from a battery (such as a 12 V cigarette lighter adaptor (CLA) connection or from the NATO connection in a vehicle)?

Simply put, if the answer to either, or both, of these questions is "yes", then it is a DC load.

Shopping Around

It is prudent to shop around when looking for appliances because power consumption varies among models even within a particular appliance class. Purchasing an energy-efficient device can be more expensive up front, but could mean future savings in energy costs as well as a flexibility of use that makes the device compatible with a variety of portable power sources. DC appliances are used every day by people who have no idea that they are using a DC-powered product. When purchasing an electrical appliance, remember to ask if a 12 VDC adapter is available for the product.

$$\frac{\text{THE USEFUL WORK PERFORMED}}{\text{TOTAL ENERGY EXPENDED IN ACCOMPLISHING THE TASK}} = \textit{EFFICIENCY}$$

PORTABLE HYBRID ENERGY SYSTEMS: **HIGH EFFICIENCY BY DESIGN**

Understanding Efficiency

When a fuel-driven generator (gas or diesel) is the primary source of power in a closed circuit, it must operate continuously to provide electricity to the appliances (loads), even if the requirements of the loads are minimal or intermittent.

For example, if a 3000 watt fuel-driven generator is the sole source of power in a closed circuit, it must run continuously, producing 3000 watts of energy whether the load is 3 watts or 3000 watts. Power produced in excess of what is required by the load is lost. This is a classic example of a “low efficiency” circuit. The Hybrid Energy System is a paradigm shift that catapults closed-circuit power grids into a high-efficiency system. The Hybrid Energy System utilizes a bank of batteries to capture all of the energy produced by the generator.

Using a battery as the main source of power in a closed circuit results in “high efficiency” because power is transferred in and out of the batteries only as is necessary to keep the appliance loads operating. In a true micro-grid, multiple sources of power generation can be used simultaneously to support the battery and ensure uninterrupted power flow to the appliance loads. The battery becomes the **HEART** of the entire electrical circuit.

LOW EFFICIENCY
TRADITIONAL POWER SYSTEMS

ENERGY WASTED
*ENERGY FROM FUEL IS **WASTED** IF NOT CONSUMED BY THE LOAD*

HIGH EFFICIENCY
HYBRID POWER SYSTEMS

NO ENERGY WASTED
*ENERGY FROM FUEL IS CONSUMED BY THE LOAD OR **STORED** AS POTENTIAL ENERGY IN THE BATTERY*

Power Generation ≥ Power Consumption

Power Generated must be greater than or equal to the Power Consumed by the Load!

How to Size a Solar Stik Hybrid Energy System

Solar Stik Hybrid Energy Systems generate, store, integrate, manage, and distribute power in the most efficient manner possible. The open architecture of the design allows users to develop systems that are optimized for the environment and the requirements where it will be deployed and to quickly and easily reconfigure it if any changes occur.

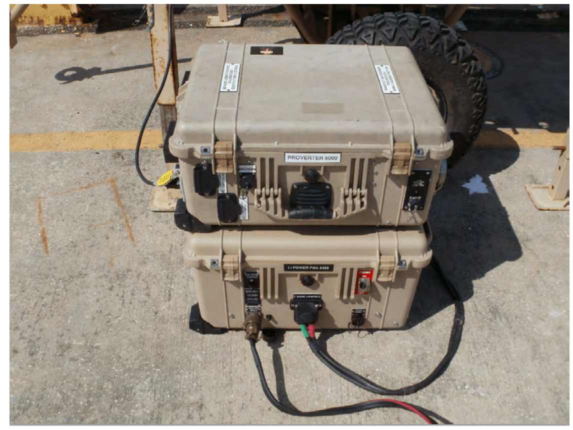
The analyses that follow demonstrate how the addition of a properly-sized bank of batteries and solar (PV) power will transform a fuel-powered generator micro-grid from an extremely low-efficiency system into a remarkably high-efficiency system.

There is a four-step process to properly configure a battery-based portable Hybrid Energy System:

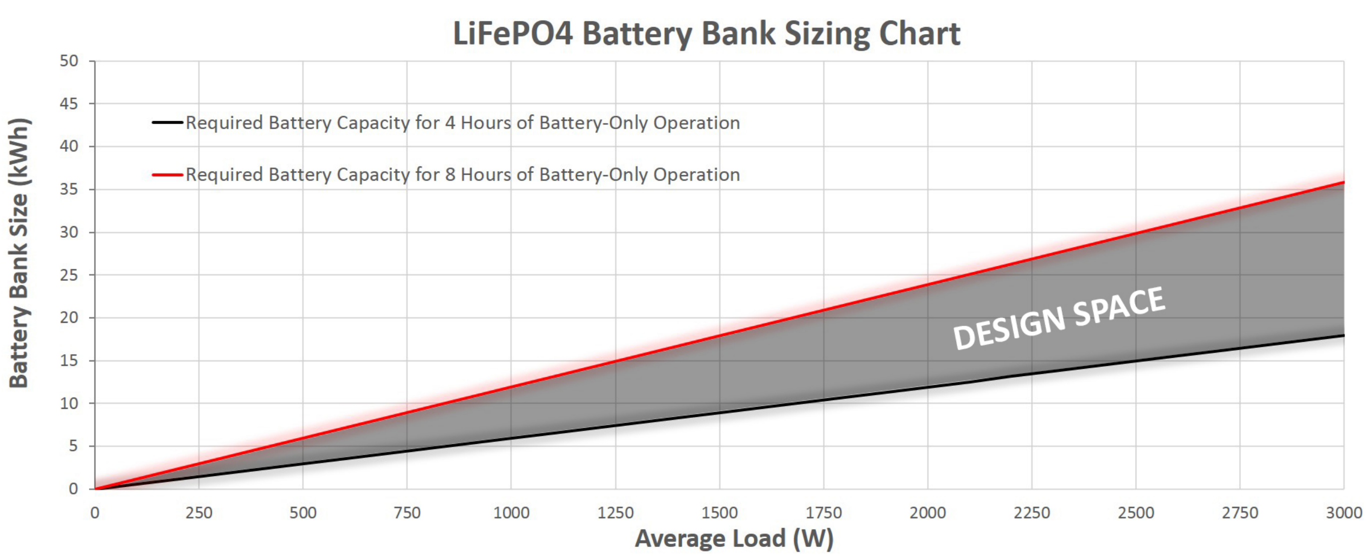
1. Understand the load profile and the application.
2. Select the appropriate battery technology and battery capacity.
3. Determine which power generation sources would be applicable to the operating environment.
4. Select the power management equipment that provides the capability required for the mission.

Sizing a Battery Bank

The load in virtually all systems is dynamic. Understanding the full range of demands (average, peak, surge) that the load will place on the system is a critical first step in the proper design of a Hybrid Energy System. The "average load" is the total energy delivered over a particular interval of time. This average load is the key determinant for calculating how large the battery bank must be. A Hybrid Energy System battery bank should be sized so that the batteries are cycled (one full discharge followed by a full recharge) about twice each day. Properly sizing the battery bank keeps system cost down by ensuring both that the correct number of batteries is purchased (i.e., not more batteries than necessary) and that batteries are not damaged due to over-cycling. Designing the battery bank to provide between 4 and 8 hours of battery-only (silent) operation will ensure that the batteries cycle two or more times in 24 hours. Additionally, this will allow the generator to start at least once a day to maintain its starter battery, engine, and fuel system.



The example graph below is a guide to determine how many kWh of LiFePO4 battery storage is required for a given average load. The red line in the graph illustrates the battery capacity required for a Hybrid Energy System to run only on battery power (silent) for 8 hours at a time, depending on the load. The black line illustrates the battery capacity required for a system to run silent for 4 hours at a time at different load values. The gray space between these two lines is the **DESIGN SPACE** that can be used to size the battery bank if the system needs to run silently for times between 4 and 8 hours.



The Science Behind Sizing

Sizing a battery bank for a Hybrid Energy System should not be left to guess work. There is a formula. In fact, the Battery Bank Sizing graph (previous page) was created using the "realistic" formula below. The math may appear daunting at first glance, but it does not need to be understood in depth. Reading through the definitions of the variables used will make the equations easier to understand.

The "ideal" equation tells us how much battery capacity would be required at various loads if every component of the system operated at 100% efficiency at any temperature for its entire lifetime–in a perfect world where the laws of physics are magically suspended. However, we have learned in other modules of Stikopedia that elevated operating temperatures, inverting current from AC to DC and the life cycle of batteries will all have an effect on the entire system. The "realistic" formula takes into account, or factors in, the the efficiency of the inverter, the effects of temperature and life cycle of the batteries. These additional factors are the extra terms in the "realistic" formula. Factoring these unavoidable losses into the "realistic" equation ensures that the size of the battery bank is not underestimated.

Credit: University of Michigan School of Natural Resources and Environment

The "ideal" equation

$$C_B = \frac{h\left(L_{AC} * \left(\frac{1kW}{1000W}\right)\right)}{DOD}$$

The "realistic" equation

$$C_B = \frac{h\left(L_{AC} * \left(\frac{1kW}{1000W}\right)\right)}{.8(\eta_{inv} * DOD * k_t)}$$

This equation provides an accurate, method to determine how much energy storage a Hybrid Energy System will need. It is often the case that power requirements change. If, for example, the load that the system serves increases, the chart or the equation can be used to calculate how much additional energy storage capacity will be required to meet the new demand. The open architecture and modular design of a Solar Stik Hybrid Energy System allows the user to quickly and easily add the required storage capacity in a plug and play fashion. Sizing DOES matter.

Solar Stik Battery Bank Sizing Calculation Variables:

C_B = battery bank capacity in kilowatt-hours (kWh)

h = # of hours of battery-only operation required

Note: If no Battery_Only Ops requirement, h=8 for approximately 2 battery cycles per day

L_{AC} = average AC load in watts (W)

0.8 = battery degradation at end of cycle life

DOD = battery depth of discharge

h_{inv} = inverter efficiency

k_t = battery ambient temperature derating

Sizing the PV array

A key feature of a hybrid system is the utilization of renewable energy sources such as photovoltaic (PV) or solar panels. The open architecture of the Solar Stik hybrid system allows users to add as much PV input as desired. Generally speaking, increasing the power supplied by PV will reduce the burden on the fuel-driven generator, thereby reducing generator run time and fuel consumption.

The chart below shows how the size of the PV array can affect the daily generator run time and fuel consumption in a Solar Stik Hybrid Power System that includes a 5 kW fuel-powered generator and a 16.8 kWhr bank of batteries. Adding PV arrays provides free power during daylight hours that effectively supplements the power that must be provided by the generator.

The data in this graph show that the greatest gains, percentage-wise, to be made are by increasing the amount of PV for average loads of less than 2500W. As the average load increases from 2500 W toward 5000 W, the percentage gains of increasing PV array size are slightly but progressively diminished.

It is important to understand that without a battery bank (in this case, 16.8kWhrs) adding PV arrays to a system would not reduce the generator run time or fuel consumption because the generator would still have to run continuously to ensure continuity of operation in the event that there was no power being produced from the PV array (for example during a cloudy dark thunderstorm or at night). The battery bank captures and stores all of the power produced by the PV array when it is produced. With a properly sized system, consistently good weather and a modest load, PV power generation can provide a tremendous reduction in the amount of time a generator needs to run and the fuel it will consume.

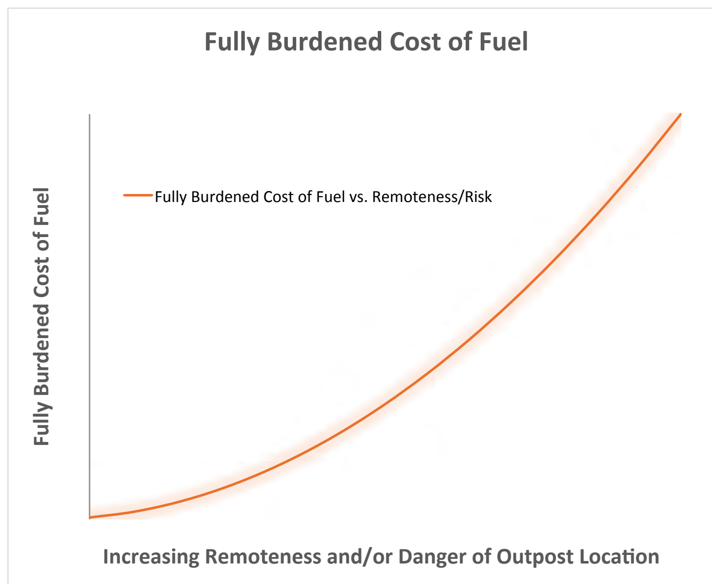
Return on Investment (ROI)

A portable, durable Hybrid Energy System is a significant investment. Lightweight yet powerful and efficient components, using the best technology available, results in a higher price point than a system designed to be installed in an easily accessible location and that will not be moved once installed. The expense of installing a Hybrid Energy System in a remote and austere location does not end once it is installed. Transporting fuel to power the generator is an ongoing expense. The more remote and austere the location, the greater that expense will be. Clearly, maximizing the efficiency of the system and harvesting as much energy as possible from renewable sources such as solar are critical components to consider when designing such a system.

The ROI of Hybrid Energy Systems in the field is difficult to determine because the Fully Burdened Cost of Fuel (FBCF) is often unknown.

The chart to the right shows that the FBCF to an outpost can increase dramatically if the outpost is located in a remote and/or dangerous area. For example, a surveillance outpost located on a mountain top far away from the supply depot may need to transport fuel and supplies using a helicopter. This outpost's FBCF would be considerably higher than a similar outpost at low elevations closer to the supply depot.

In general, the ROI of a hybrid energy system is realized in a much shorter time if the system is to be deployed in remote or dangerous locations.



SOLAR STIK®

STIKOPEDIA

MODULE TWO

The Solar Stik System

THE 5 TENETS OF A **SOLAR STIK SYSTEM**

Use and Design

The basic philosophy of design for the Solar Stik System encompasses five primary tenets:

Portability

- Lightweight, modular, human-portable components
- Engineered and design-optimized for mobility
- D.O.T. approved for Land, sea, and air transport
- Power spectrum up to 10kW

Adaptability

- Open architecture allows flexibility of deployment and operations as technology advances
- “Plug & Play”, polarized connections
- Reduces dependency on any ONE technology
- Allows selection of SPECIFIC capabilities for an application
- No “planned obsolescence” in system design; allows adoption of advanced technologies into the system architecture as they mature.
- Improves effectiveness of older technologies (such as older fuel-driven generators)
- Maximum configuration options based on application, available resources, and logistics

Scalability

- System can be scaled up or down as conditions change
- Scaling provides BALANCE between capabilities
- Allows specific capabilities to be maximized:
  - Solar panels for autonomy– ”independence from grid”
  - Energy storage for “silent operations”

Durability

- “NO FAILURE” rule is applied:
  - Manufactured in America using domestic-source components
  - Ruggedized - MIL-810G Standards applied to construction
- Intuitive setup and operation
- Field-serviceable components

Autonomy

- Battery is the “common thread”:
  - Foundation of high-efficiency electrical circuit
  - All components operate in support of a battery
  - Renewable technologies are prioritized over traditional resources
- Provides as much “self-sufficiency” for the operator as is required for the application

SOLAR STIK
SYSTEM ARCHITECTURE

Product Categories

There are four general categories of components that constitute a closed-loop circuit or micro-grid.

Power Generation

Sources can include solar, wind, fuel-driven, fuel cell, vehicle, or water energy.

Power Management

This can include AC and DC sources, funneling, distribution, and line conditioning.

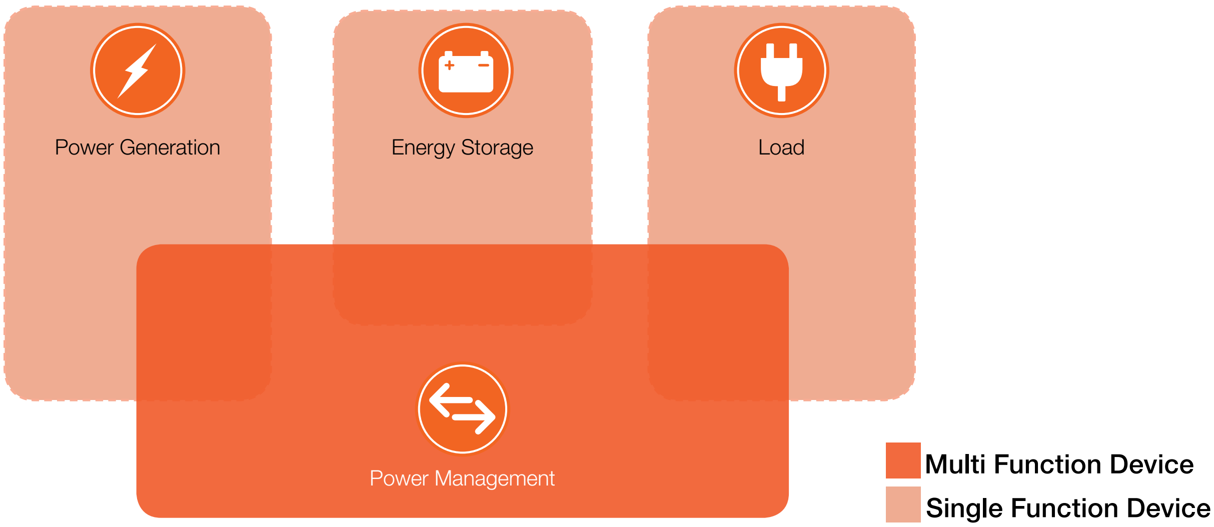
Energy Storage

Energy is stored in rechargeable batteries such as lead-acid or LiFePO4.

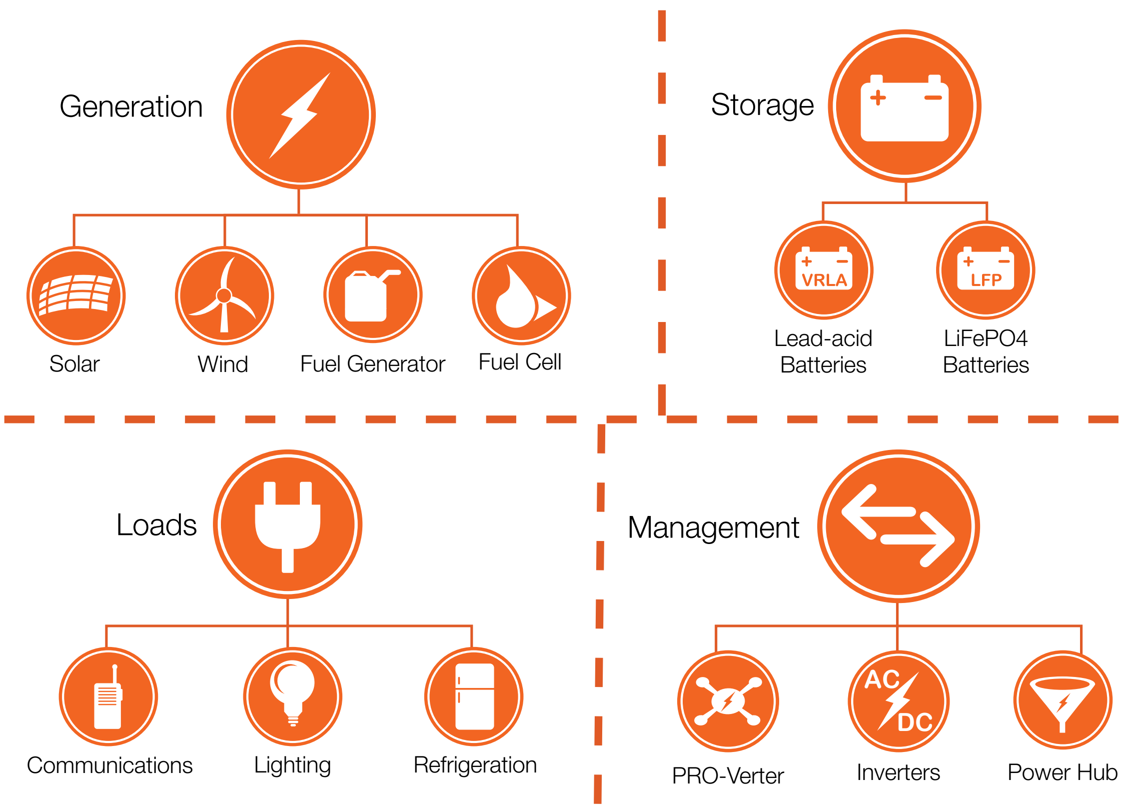
Loads

A load includes any appliance that uses power, such as lighting or refrigeration.

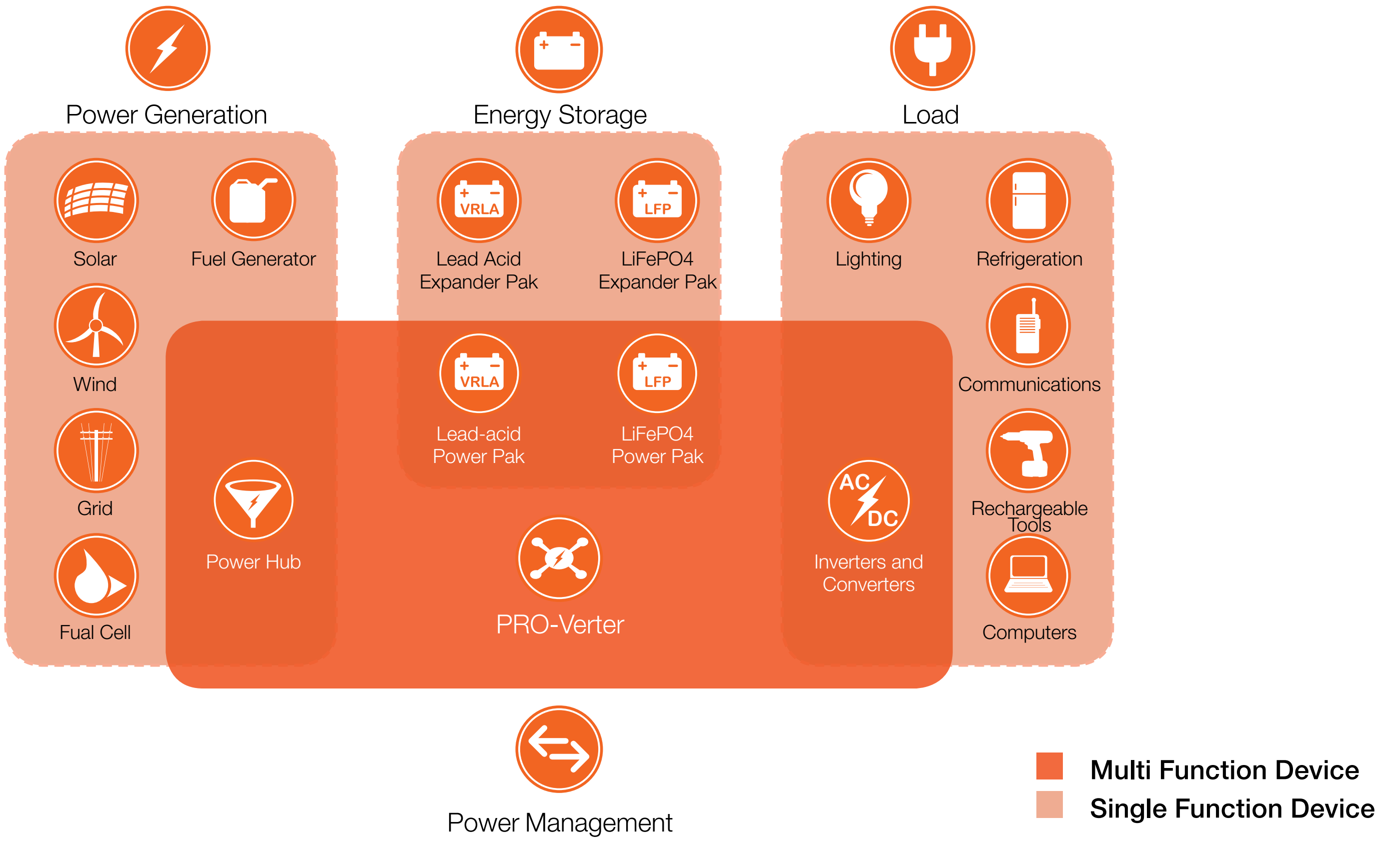
Each product category is designed to be used in conjunction with other product categories in a systematic fashion. Each category has components that can serve only one function (such as a battery) or that can serve multiple functions (such as a PRO-Verter). The graphic below shows the relationship between the categories and how they work together based on their role in a System.



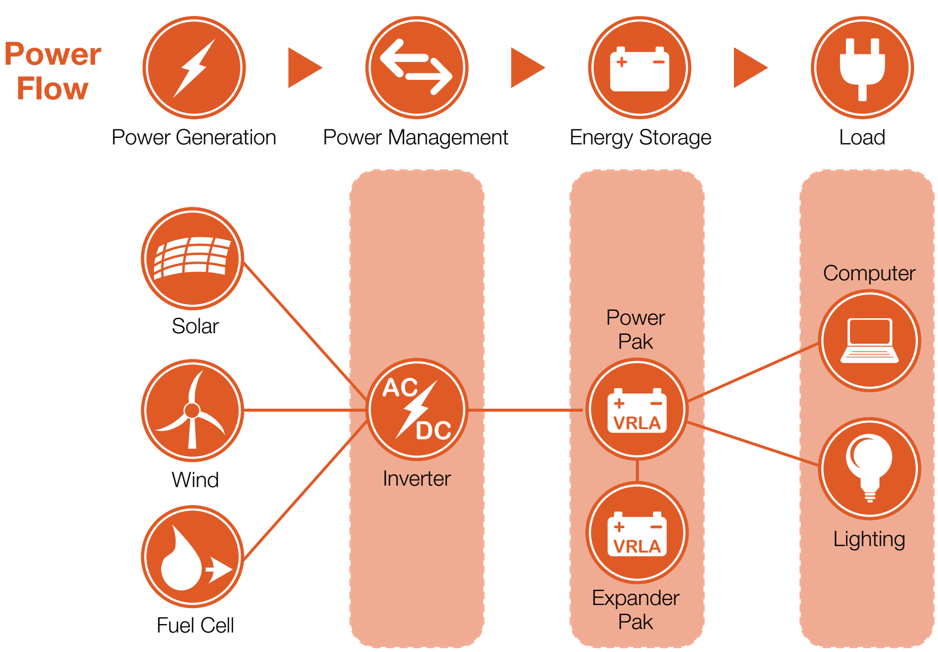
Components from at least three product categories must be present in order to provide the operator with a high-efficiency electrical circuit.



The modularity of the system allows the user to assemble either a basic (small) or a complex (large) system according to their requirements. All Solar Stik Systems can be modified, expanded, or contracted as conditions warrant.



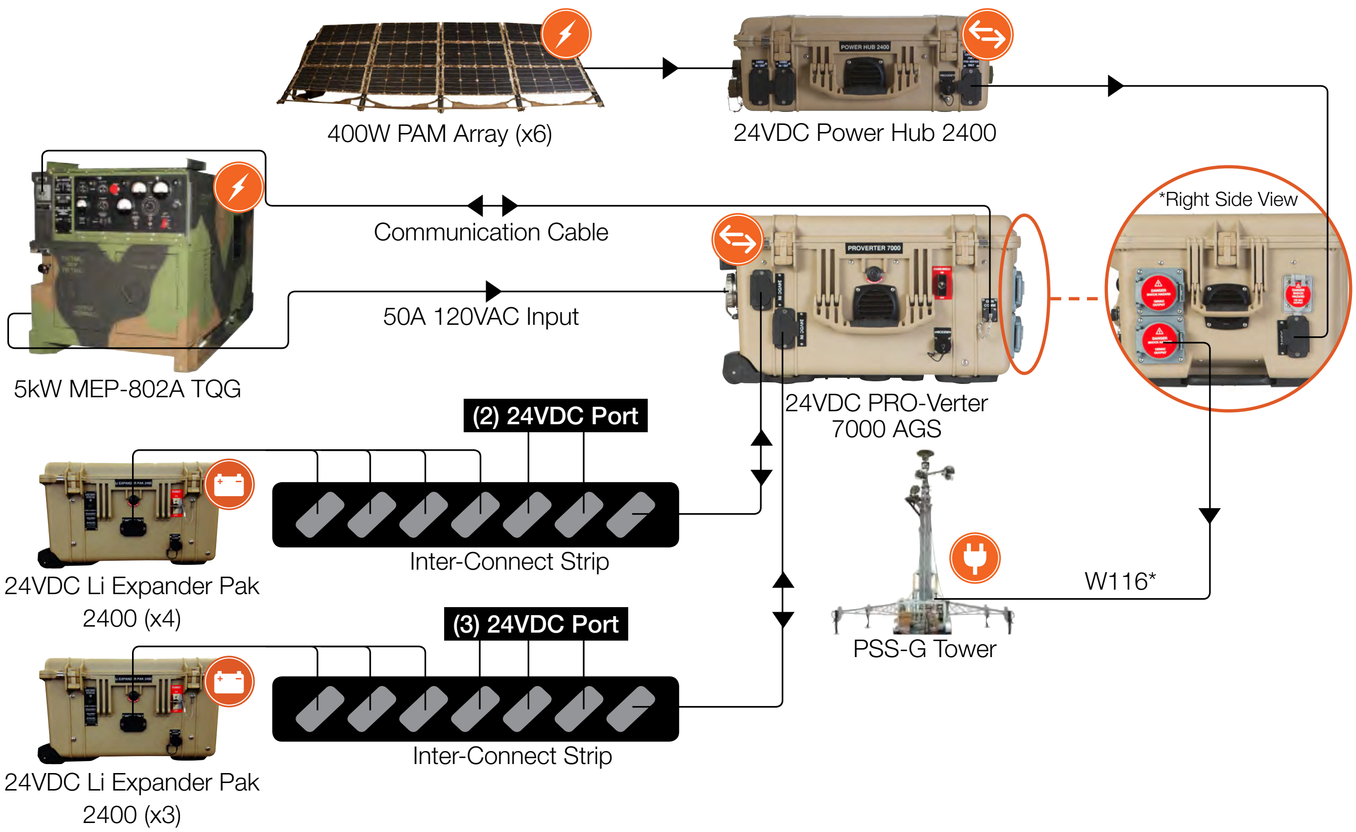
Power flows through a closed-loop system as shown in the diagram below.



Examples of the Different System Architectures

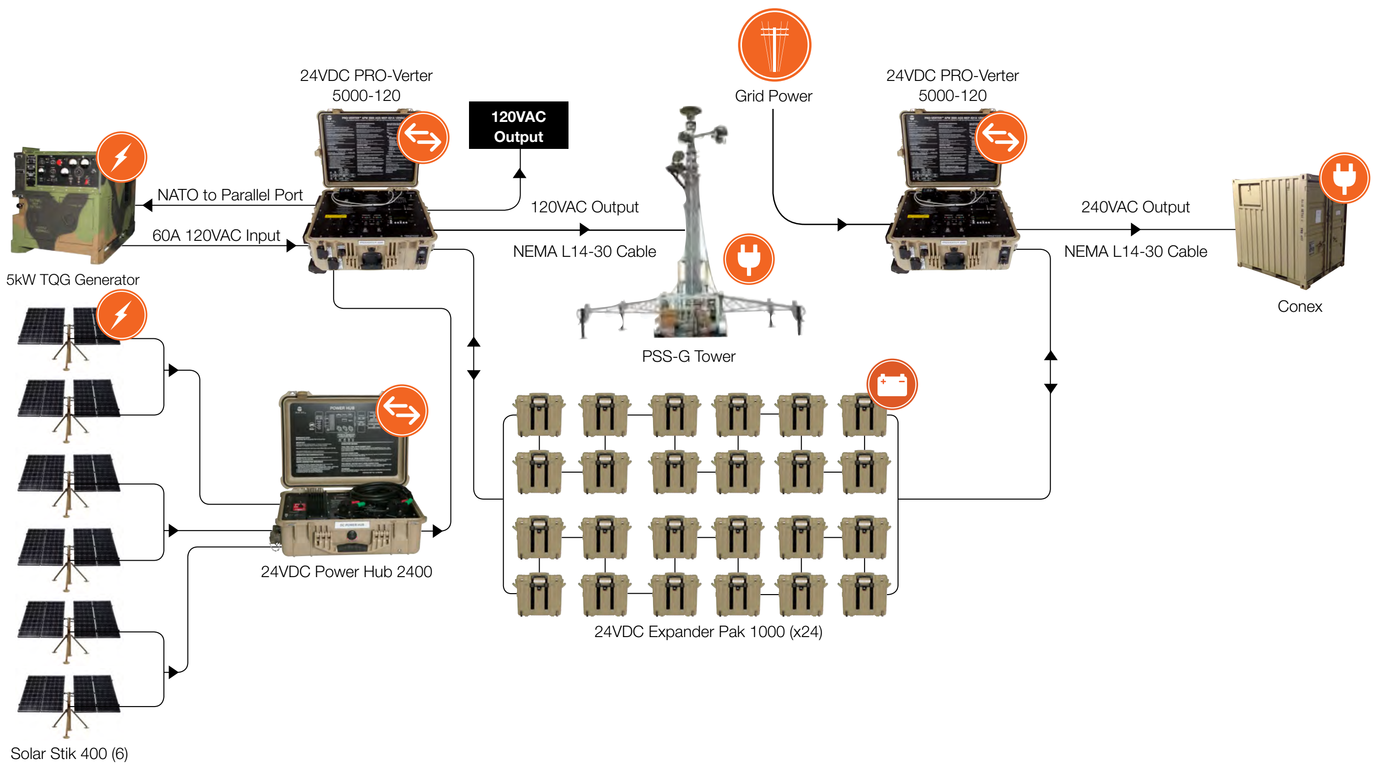
Consolidated or "Closed-loop" Power Model

A Consolidated Power Model is characterized by its ability to operate as an "island", independent from grid power. It can include, but is not limited to, one generation source, one energy storage component (battery bank), and one power management device.



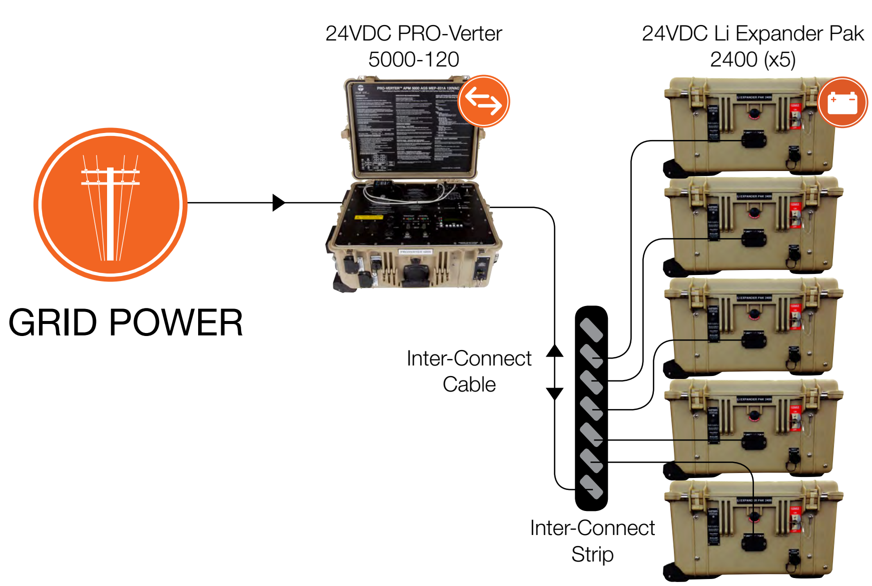
Distributed Power Model

In a Distributed Power Model, multiple stations can function in concert, but still in a closed-loop configuration when conditions warrant. Power is generated from multiple sources, including the grid and prime-power sources. In the example below, two PRO-Verter 5000s are used with a common battery bank. One PRO-Verter is connected to a TQG while the other is connected to a grid AC source.



Uninterruptible Power Supply (UPS) Power Model

In a UPS Power Model, a bank of batteries is charged with power from an AC source such as the grid or a primary generator power. The energy stored in the batteries can be used to power loads in the event that grid or generator power becomes unavailable.



INTER-CONNECT **SYSTEM**

"Plug & Play" Inter-Connection System

The Inter-Connect Network is designed for two functions.

1. Safety - Reducing simple mistakes in the field as the first line of defense against failures

2. Operational Benefits - Rapid setup, modification, and scaling of the system architecture

Safety First

The Inter-Connection system promotes safety within the circuit by minimizing the potential for a reverse-polarity connection. It protects from overloads and short circuits with a network of breakers placed strategically throughout the circuit. If a problem occurs in a leg of the Inter-Connect circuit, then the affected leg will automatically disconnect from the primary network, leaving the other circuits functioning. If a major failure occurs in the circuit, then the entire network will shut down.

"It protects from overloads and short circuits with a network of breakers placed strategically throughout the circuit."

Operational Benefits

Many operators who use a Solar Stik System may have limited experience using a battery-based electrical circuit. The Inter-Connection System uses a unique set of polarized Plug & Play connections called Inter-Connectors. These connect DC-powered components together, and serve as the electrical skeleton within the system's architecture.

The Inter-Connect cable is most easily understood as an extension of the primary battery through a DC circuit. Effectively, it acts as a bus. It provides a convenient way to add or remove appliances, manage devices, or even provide additional batteries in a micro-grid configuration without the need to cease operations while making the change. It is simple enough that a single person can safely set up and configure the micro-grid in a matter of minutes.

Inter-Connect cables are supplied with compatible system components such as Expander Paks, Wind Stiks, Power Hubs, PRO-Verters, and PRO-Cells.

Differences Between Inter-Connectors

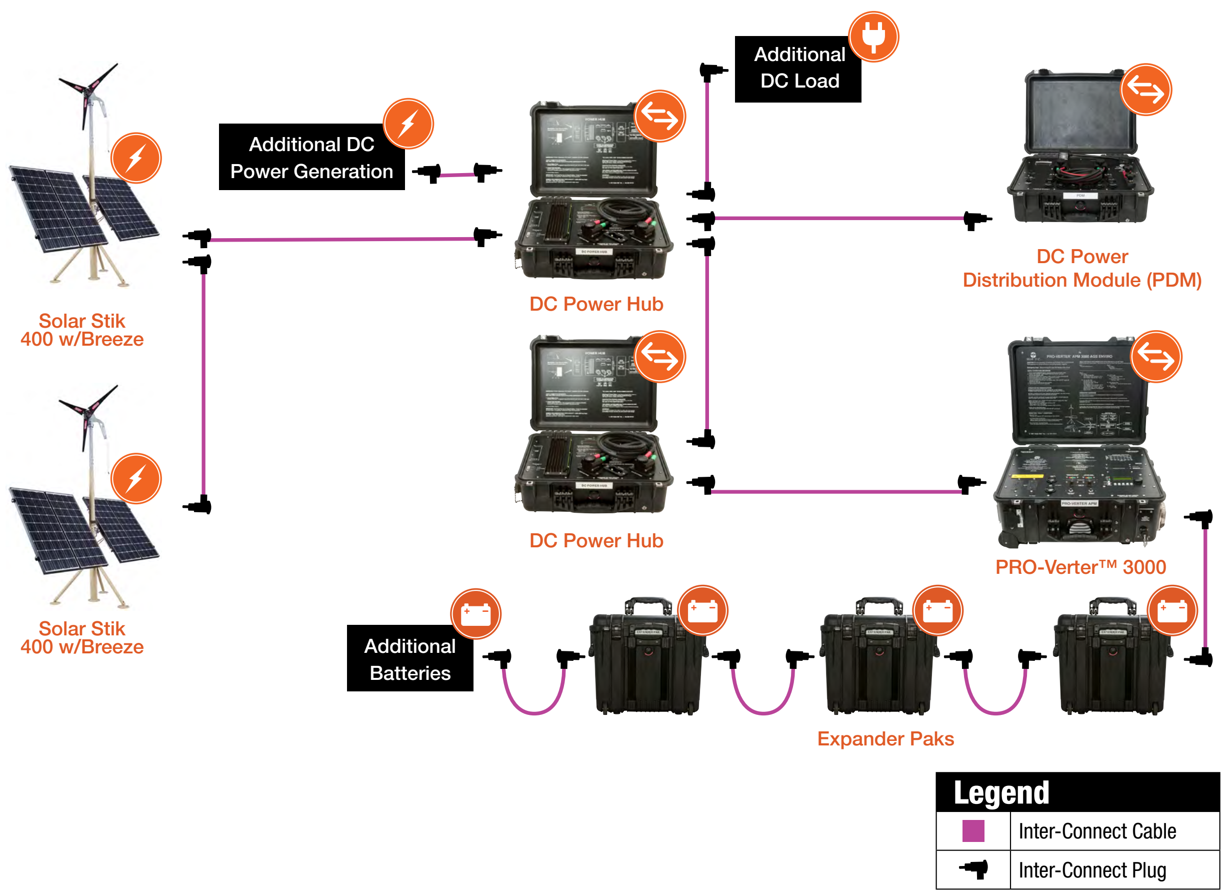
12VDC

- 100 A maximum current
- Used in 12 VDC applications
- Inter-Connect plug snaps into place and features a button release
- Crimp connectors
- NOT field adaptable–CANNOT be modified in the field

24VDC

- 200 A maximum current
- Used in 24 VDC applications
- Inter-Connect lug twist-locks into place
- Mechanical connectors–ring terminals
- Field adaptable–CAN be modified in the field

An Inter-Connect Network Example



STIKOPEDIA

Credit: Martin L

MODULE THREE

Electricity and Circuits

WATTS, VOLTS, **AND AMPS**

The Characteristics of an Electrical Circuit

The more an operator understands how to effectively design and use an electrical circuit that is based on stored power principles, the more autonomy he can achieve.

Truly understanding the necessary characteristics of a battery-powered, or direct current (DC), electrical circuit requires understanding the following:

- How to determine the voltage and amperage in a circuit
- How to determine the power requirements (measured in watts) for each individual appliance (load) while operating
- How to determine the power consumed by an appliance over a 24-hour period, typically measured in kilowatt-hours (kWh)
- How to properly size a battery bank to meet the load requirements
- How to determine the amount of power needed to replace energy used by the load
- How to choose a solar, wind, or hybrid power system that meets or exceeds the total load requirements
- How to determine the total power generated and consumed in an closed-loop electrical circuit

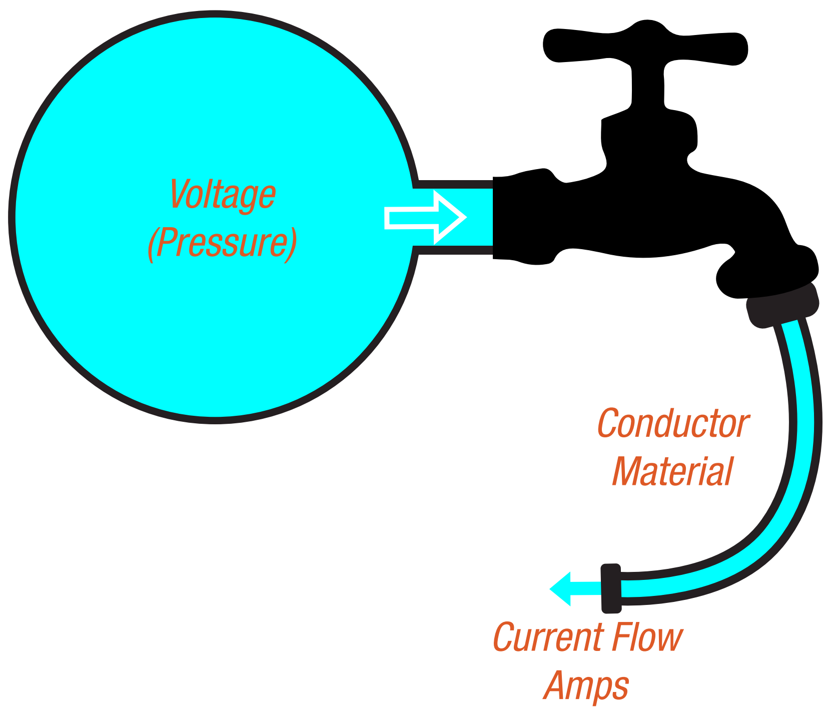
Basics of Electricity

Volts - “Deal with the Pressure”

Voltage is a measurement of electromotive force in a circuit. It can be described as the amount of pressure, force, or “push”.
For example, if a circuit has a measurement (or rating) of 5 Volts (V), then electricity is pushed through the line with a force of 5 V.

Why is this important? Every circuit has resistance in it. Resistance impedes the flow of electrons through a conductor. Voltage can be used to ensure that the effect of resistance is minimized.

Imagine a spigot that has a lot of water pressure. Turning on the spigot results in a very strong flow with lots of water. The force of the water is a result of the pressure in the line. However, when a long and narrow hose is connected to the spigot, you may notice that the water pressure is not as great at the other end of the hose.



What caused the drop in pressure? When the water is flowing unrestricted from the spigot, it has a certain amount of pressure. When the water is forced into a smaller conduit, the resistance to the water flow is increased; thus, the flow is restricted and the pressure falls. If the pressure at the spigot were to increase, then the water flow through the smaller hose would also increase relative to the pressure at the spigot.

Amps - “Go with the Flow’”

Amperage is a measurement of electricity flow through a circuit. Specifically, it is a measurement of the amount of electrons that flow through a conductor material (such as a copper wire).
For example, a wire conducting electricity may have a flow measured (rated) at 5 Amps (A).

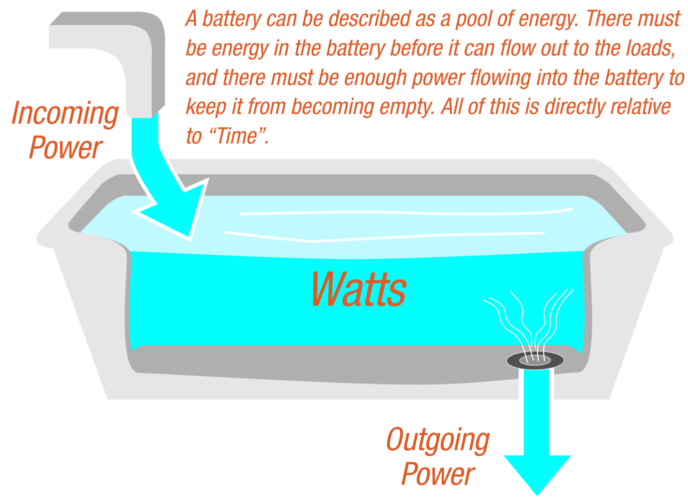
Why is this important? As with voltage, amperage has a lot to do with the resistance of the circuit. Resistance in an electrical circuit impedes the flow of electrons through a conductor; therefore, every circuit conductor has a maximum flow rate assigned to it that it can safely handle.

The aforementioned hose analogy can also be applied when describing amperage, as the flow of electricity through the circuit can be measured in the same way we measure water flow.

In that example, the hose has a maximum water flow rate based on the pressure of the water supplied and the size of the hose itself. When a long hose with a small diameter is connected to a spigot supplied with a larger diameter pipe (thus, a high rate of water flow), you may notice that the water pressure or flow is diminished as it exits the hose. This reduction of flow caused by the smaller hose is similar to the resistance of an electrical conductor: it caused a reduction in the amps that flow through it based on the resistance (size and length) of the conductor.

Watts - "The Tie that Binds"

Wattage is a measurement of electricity generated or consumed in a circuit. There is a simple rule to remember when determining watts: "a Watt, is a Watt, is a Watt". The amount of watts generated in a circuit must be equal to or greater than the watts consumed by the load.

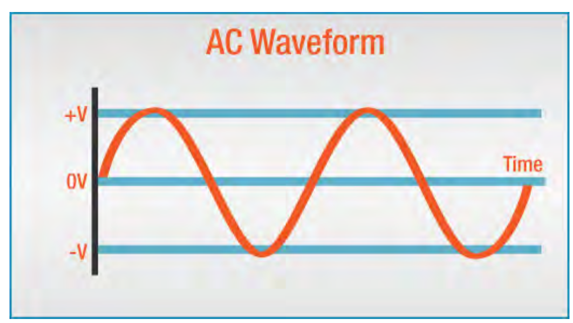


Watts never change as electricity flows through an electrical circuit; they are a constant value. Watts (W) can be generated and consumed, and they may be reflected as different amounts, but they are usually only measured at the generator and the load.

What happens in between the watts-generated and the watts-consumed values is what ends up being measured in volts and amps.

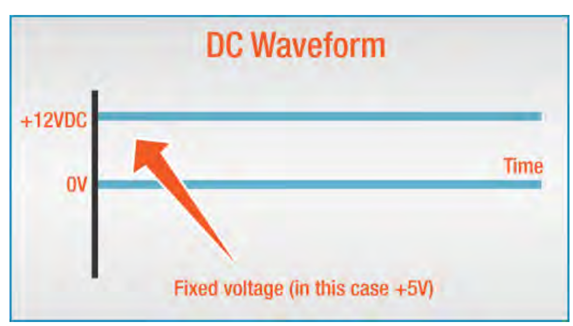
AC and DC Current

There are two commonly used types of electricity: alternating current (AC) and direct current (DC).



Most small DC systems use 12 or 24 volts (normally expressed as 12 VDC or 24 VDC), and most AC systems in the United States use 120 or 240 volts (120 VAC or 240 VAC).

- If your power is supplied by the utility grid or a gasoline generator, it is probably an AC circuit.
- If your power comes from a battery, it is a likely a DC circuit.



The Load

A load is anything and everything that consumes energy from your electrical system. All electrical systems are constructed based on the amount of energy that the load will require.

There are three factors that combine to successfully supply power to the load:

- Volts (V)
- Amps (A)
- Watts (W)

Calculating the load is the most important part of designing a portable power system. It is incumbent on the operator to understand fully the load, including its power requirements (voltage, amperage, and wattage), the operational characteristics (intermittent or constant), and the type of power (AC or DC) necessary to support it.

Formula for Determining the Electrical Characteristics of a Circuit

The formula to determine the power characteristics of an electrical system is as follows:

Voltage multiplied by Amperage, equals Watts (Power)

To the seasoned electrician, this formula is actually represented by the following:

$$E = I \cdot R$$

E = volts; I = current in amps; R = resistnace in Ohms
But for the purposes of this course, we will use a variation of Ohm's law:

$$V \cdot A = P$$

Variations of this formula can be used to determine the values of all three factors:

$$V \cdot A = P$$
$$P \div A = V$$
$$P \div V = A$$

The Battery — The Heart of a High-Efficiency System

How does the total system load relate to the battery or batteries, or battery bank?

Batteries store energy, and often have ratings corresponding to the total amount of energy stored within the battery. This is known as the battery capacity.
It important to have the proper battery capacity in an electrical circuit for many reasons:

- Proper capacity should be able to supply the total power required by the load in a system.
- Proper capacity should be able to be fully recharged from the chosen power generation source or sources on a regular interval.
- Proper battery capacity ensures that there is enough energy to power your load between charges.

When a battery is used as the primary source of energy for a load, energy only flows from it in direct proportion to the power that is required to support the load. This catapults the entire circuit into a "high-efficiency" model.

Energy and Battery Capacity

Amp-Hours - Generally, a battery will have a label that rates its energy storage in amp-hours (Ah). This rating refers to how many amps can flow from the battery to the load over a period of time to consider the battery discharged, or empty of "potential" or stored energy.

For example, if the battery label reads "125 Ah reserve", then it means that at full charge it should be able to provide 25 amps continuously for 5 hours.

$$25A \cdot 5h = 125Ah$$

At the end of the 5-hour duration, the battery would be considered discharged and out-of-service until recharged.

Watt-hour - A watt-hour is the total power consumed over a one-hour period time. If you have the battery ratings for voltage (V) and amp-hours (Ah) you can also determine the watt-hours (Wh) stored in the battery. Just as the product of volts and amps is equivalent to power, volts multiplied by amp-hours is equal to watt-hours.

$$V \cdot Ah = Wh$$
$$12\ V \cdot 100\ Ah = 1200\ Wh$$

A 12V 100Ah battery can supply up to 1200Wh of total energy to a load.
Finally, it is common to refer to power in groups of 'one thousand Watts', or Kilowatts.

Kilowatt-hours - Kilowatt-hours is abbreviated kWh; thus the appliance above that uses 1200 Wh of power could also be expressed as using 1.2kWh.

EXAMPLE

You're Going Camping!

Imagine that you own a recreational vehicle and need to build a DC electrical system to power it. Your camper will have two appliances that comprise the load in its electrical system: a 12VDC refrigerator, and a 12VDC lamp, with each appliance consuming different amounts of energy.

Most electrical appliances have a data plate or tag that tells what type and how much power is necessary to operate the appliance. If no data plate is present, then the manufacturer's product literature report the values. Depending on the manufacturer, you may find the operating energy requirement rated in Watts or Amps. If you know the Voltage, you can use either value (Watts or Amps) to determine the other.

Let's say that a 12VDC lamp consumes 25W of power, and you need to know how much current (amps) it will draw. Apply the formula as follows:

$$P \div V = A$$
$$25W \div 12V = A$$
$$= 2.1A$$

Now consider the refrigerator. Assume the power consumption rating given on the refrigerator's data plate is 60W. Simply complete the formula using the system voltage to determine the amperage:

$$P \div V = A$$
$$60W \div 12V = A$$
$$= 5A$$

The refrigerator draws 5A of current when operating.

Both watts and amps can be tallied as a sum-total by adding the values together. To determine the total load values for the recreational vehicle's DC system—or the system's "total load"—simply add the values of the wattage or the amperage for all of the individual appliances together.

2.1A + 5A = A
= 7.1A total

In the example above, the total amp draw for the lamp and the refrigerator is 7.1A.

25W + 60W = W
= 85W total

In the example above, the total watt consumption for the lamp and the refrigerator is 85W.

Lastly, calculate the total values for the system. The same formula applies and should reflect the overall characteristics of the circuit.

V · A = P
12V · 7.1A = 85.2W

It is common practice to round the numerical values for watts to the nearest whole number. In this case, the formula would reflect:

12V · 7.1A = 85W

BATTERY-BASED **ELECTRICAL CIRCUIT SETUP**

There is a three-step process to properly configure a battery-based portable power circuit:

1. Calculate the load.
2. Calculate battery capacity required.
3. Calculate generation required.

Performing these three basic steps will ensure that your system will function properly and provide years of reliable service to your application.

Calculate Your Load's Actual Daily Energy Requirements

In the recreational vehicle example earlier, we determined that the refrigerator and lamp draw a total current load of 7.1A when both appliances are operating. However, this did not take into account that the lamp may not be in use all the time, or the refrigerator could be in operation for only 20 minutes every hour.

To get an accurate picture of a system's total daily requirements, you will need to get the sum-total of hours per day of refrigeration and lamp operation time. Let's say that you added it all up and estimated that the total amp draw from the batteries was 7.1A for 8 hours in a 24-hour period:

$$7.1\text{A} \cdot 8\text{h} = 56.8\text{Ah}$$

This means that the lamp and refrigerator are consuming about 57Ah per day. In the same manner, the Watt-hours (Wh) can also be calculated. If the refrigerator and lamp consume a total of 85W and operate for a total of 8 hours daily:

$$85\text{W} \cdot 8\text{h} = 680\text{Wh}$$

Then the total Watt-hours consumed in a 24-hour period would be 680Wh. Even when labeled differently, the appliance energy requirements are exactly the same. With the appliances operating on 12V multiplied by 56.8Ah, a total load of 681 Wh is consumed:

$$12\text{V} \cdot 56.8\text{Ah} = 681\text{Wh}$$
$$(= 0.68\text{kWh})$$

The total daily energy requirement for the light and refrigerator is about 0.7kWh. Now that we know how much energy we need for the light and refrigerator on a daily basis, we need to determine the correct battery capacity and how to replace the 57Ah or 0.68kWh of power that was consumed from the battery during one day.

How much battery capacity is required for my load?

Determining the correct battery capacity to support a load requires that the total daily load requirements be known. The next step is to consider the type of battery for the application. For the purposes of this discussion, we will focus only on the lead-acid battery, as it is still the most commonly used type.

Generally, lead-acid battery cycles should be limited to 1 to 2 cycles daily, to a maximum of 80 percent depth of discharge.

In keeping with this rule, there is a simple formula for determining the battery capacity required for a load:

Total Daily Load Power Requirements (Wh) multiplied by two (2).
Using the calculations from the recreational vehicle we know that the total daily electrical requirements are 680Wh, or 56.8Ah. If we apply the battery formula:

$$680Wh \cdot 2 = 1360Wh$$
$$1360Wh \div 12V = 113.3Ah$$

We find that we should use a 12V battery that is rated for about 113.3Ah or 1360Wh of energy storage.

Selecting a Power Generator to Recharge the Battery

The generator(s) you choose should be able to fully recharge the battery once a day, thus limiting the battery cycles to one to two times daily.

In keeping with this rule, there is a simple formula for determining the generation required to recharge a battery:

Total Battery Capacity (Wh) multiplied by 1.25 (1¼)

Applying the formula to the above example yields:

$$680Wh \cdot 1.25 = 850Wh$$
$$850Wh \div 12V = 71Ah$$

We find that we should use a generator that is capable of producing at least 850Wh (71Ah at 12V) of daily power to keep the battery charged and cycles to a minimum.

Operating AC Appliances from a DC Circuit

Not all appliances that operate in a closed-loop circuit will operate on the same voltage or power type (AC or DC).

If a load requires 120VAC power to operate, but the battery circuit provides 12VDC power, then an inverter should typically be used.

Inverters, as the name implies, invert DC power into AC power while also boosting the lower (typically) DC voltage to the higher AC voltage. Inverters consume power in the process of inverting, and in doing so, contributes to the system load. The less power an inverter consumes the more "efficient" it is. Each inverter has an efficiency rating.

If an inverter is to be used, the following questions must be answered:

1. What size inverter do I need for my load?
2. How much power does an inverter use while operating?
3. How does it affect the total load requirements in my system?

Step 1: Understanding “Inverter Efficiency”

Imagine you have a microwave oven and the manufacturer’s plate indicates that it requires 800 Watts to operate. We can easily determine the DC amperage it would require if it were to operate directly from a 12V battery:

$$\mathbf{P \div V = A}$$
$$\mathbf{800W \div 12V = A}$$
$$\mathbf{= 67A}$$

Since an inverter must be used, we have to calculate the “inverter efficiency”. If inverters were 100 percent efficient, then all of the power flowing from the battery would be inverted for use by the load, and the inverter would consume no power at all.

In reality, however, inverters consume some of the power that flows from the battery while inverting. This results in an increase in current flow from the battery to support the load, and an increase in the total load requirements.

Let’s assume that an inverter has a “efficiency rating” of 80 percent. This means that only 80 percent of the power that is flowing from the battery can be used for the load. If the load is 800 Watts, then the flow of current from the battery must be increased by 20 percent to keep the inverter and the load operating:

$$\mathbf{800W = P \cdot 80\%\ efficiency}$$
$$\mathbf{800W \div 80\%\ efficiency = P}$$
$$\mathbf{P = 1000W}$$

The total load in the circuit is 1000W.

Step 2: Effect on the Total Amps Flowing from the Battery

Now that we know the total load on the circuit, taking inverter efficiency into account, we can calculate the amps:

$$1000W \div 12V = A$$
$$= 83A$$

The inverter and the microwave will collectively require 83A of current from a 12VDC battery source to operate properly.

Step 3: Sizing the Inverter

It is recommended that the inverter have a minimum power rating of 125 percent of the total load. Continuing with the example above, if the microwave load is 800W, then the following formula would apply:

$$800W \cdot 125\% = P$$
$$= 1000W$$

In this case, an inverter with a continuous output of 1000W should be used.

Further Reading

Batteries and inverters vary widely and must be chosen carefully in order to meet the requirements of the application. Learn more about Batteries and Inverters in Modules Five: “Battery School “and Module Six: ”Inverter School”.

SOLAR STIK®

STIKOPEDIA

MODULE FOUR

Solar School

SOLAR PANEL TYPES **AND APPLICATION**

Purchasing solar panels is the only direct cost associated with using them. Once you own them they produce power for free as long as there is sunlight.

Additionally, solar panels will generate power anytime there is daylight, even on a cloudy day, making them a guaranteed power source. Other renewable energy sources, such as wind power, may not be as reliable.

Standard Test Condition (STC) Ratings

There are many different manufacturers of solar panels and types of solar panels. A solar panel is a set of photovoltaic (PV) modules or "cells" electrically connected and mounted on a supporting structure. The chemistry, construction, and performance vary greatly between panels. To make an apples-to-apples comparison between the types of panels, a uniform method of operational testing has been defined, and is known as the Standard Test Conditions (STC).

Standard testing uses the same conditions for all panels: direct, incident sunlight at an intensity of 1000 W/m², a cell temperature of 25°C (77°F), and an air mass of 1.5 (air mass, or density, affects the amount of sunlight that reaches the Earth's surface).

Each module is rated by its DC output power under standard test conditions (STC) by the manufacturer.

Operating factors for any Solar Panel

Three factors affect any solar panel’s ability to generate power:

Direct Sunlight

Operating Temperature

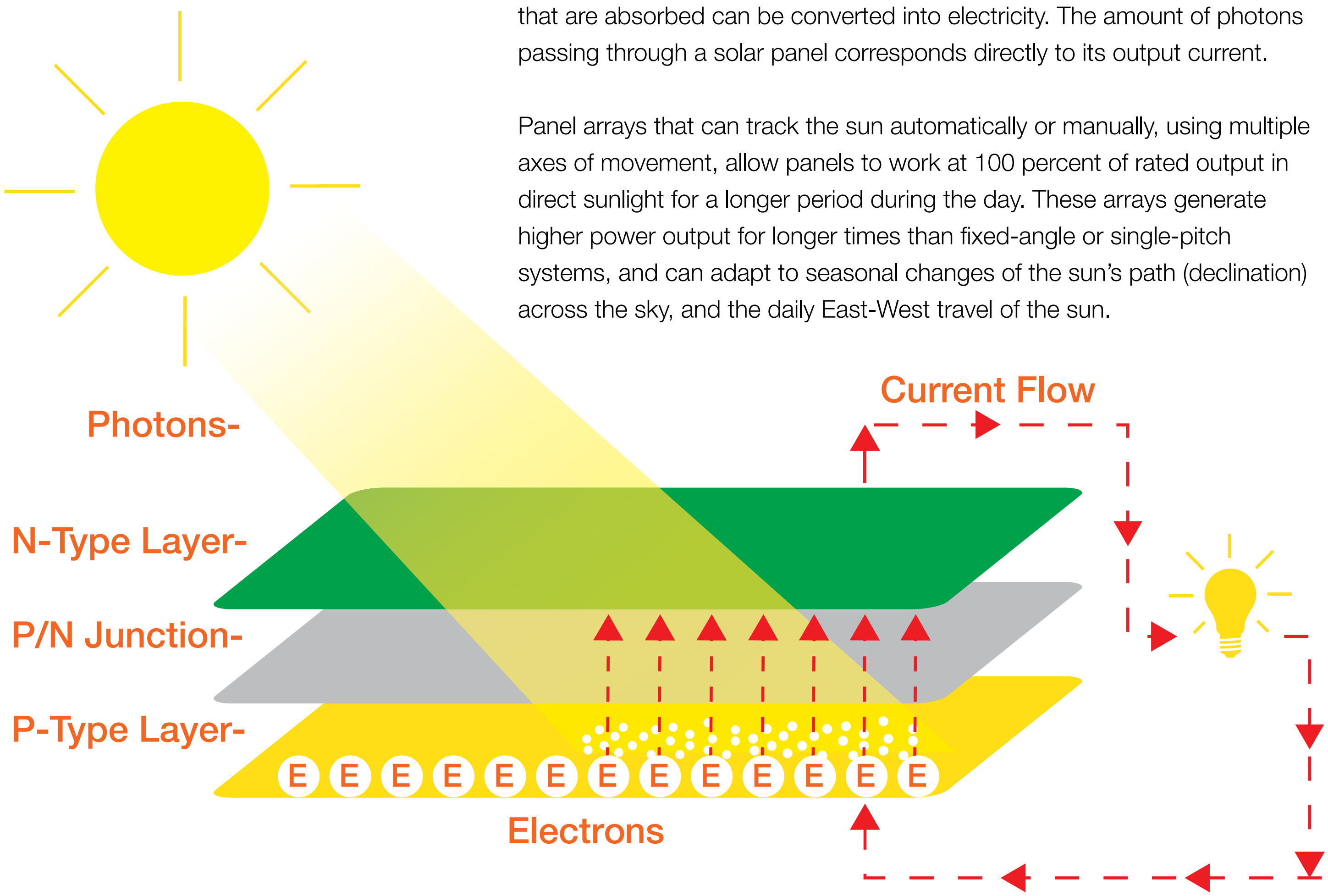
MPPT Maximum Power Point Tracking

Direct Sunlight

Solar panels operate at their rated capacity only when placed in direct sunlight, allowing photons to pass directly into the cells. The photons cause electrons to flow from the positive field of a solar cell (P-type layer) to the negative field (N-type layer). This flow of electrons is called amperage, or current.

Sunlight hitting a solar panel directly will be absorbed most efficiently resulting in a greater electrical current. If the sunlight hits the solar panel at an angle, the photons will be reflected more and absorbed less. The sunlight is “Direct” when it is within a 15 degree angle (in any direction) of being perpendicular to the solar panel. This translates to about a 30 degree angle “window” where the panel will operate at maximum output. Only photons that are absorbed can be converted into electricity. The amount of photons passing through a solar panel corresponds directly to its output current.

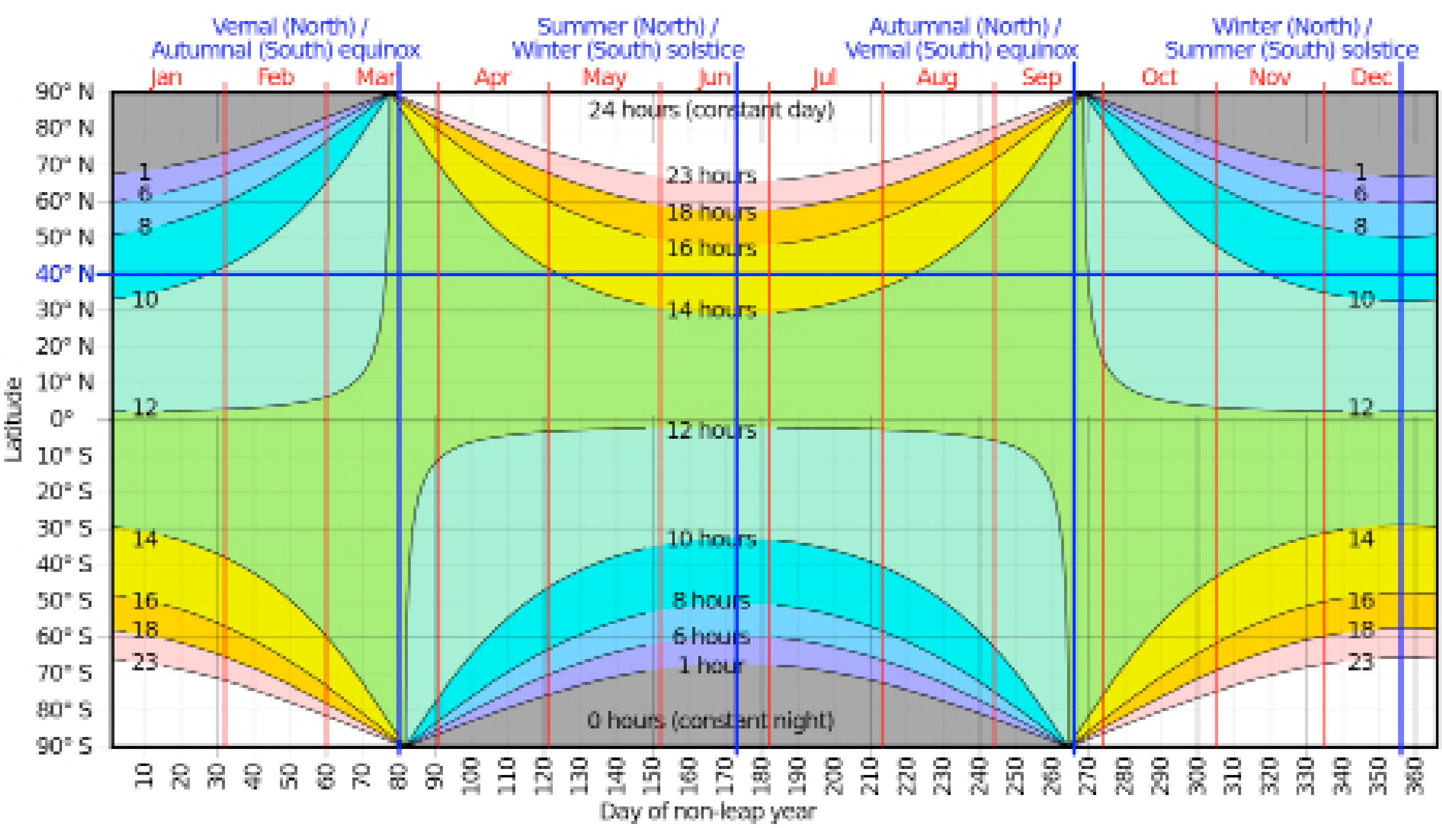
Panel arrays that can track the sun automatically or manually, using multiple axes of movement, allow panels to work at 100 percent of rated output in direct sunlight for a longer period during the day. These arrays generate higher power output for longer times than fixed-angle or single-pitch systems, and can adapt to seasonal changes of the sun’s path (declination) across the sky, and the daily East-West travel of the sun.



The sun rarely passes directly overhead during the course of a year. Most solar panels mounted in fixed-angle or flat positions (facing straight up) will operate at reduced capacity, even during the noon hour. Single-axis solar panels often are adjusted only for seasonal changes in the angle of the sun (horizontal axis), but have limited ability to track the daily East-West progression of the sun's travels. Single-axis tracking is extremely important for arrays that are located in far northern or southern latitudes.

A solar array that has a multi-axis tracking system can often be as effective as a fixed-mounted panel system two to thre times its size. Tracking requires as few as three daily panel adjustments to produce 100 percent of their rated power output all day long. With tracking, users can achieve 200 to 300 percent increases in power output over stationary or single-axis systems, depending on geographic location and time of year.

The chart below illustrates how much sunlight one can expect during any time of the year at any latitude and in either hemisphere. The horizontal blue line highlights the seasonal variation of the hours of sunlight at 40° N latitude. This parallel crosses through or near to Chicago, Istanbul, Beijing, and Madrid.



Credit: Wikipedia user Cmglee

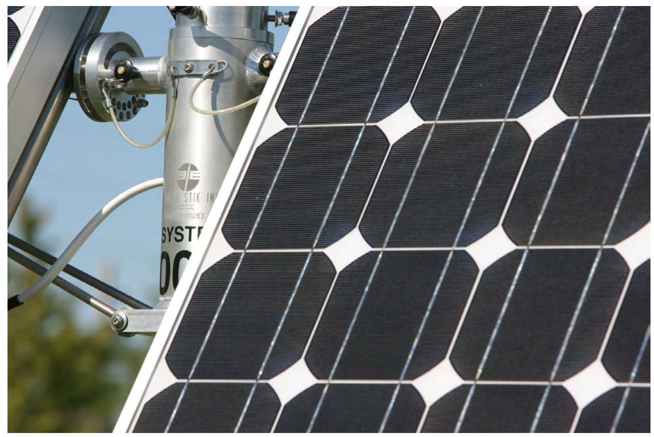
Operating Temperature

Temperature plays a key role in a solar panel's ability to produce power. A rule to remember when using solar panels: Cooler panels generate more electrical power than hot panels. As a panel becomes hotter, its efficiency is degraded.

There are two factors that affect heat degradation:

- Solar panel (PV module) construction
- Mounting of the solar panel

Construction



Photovoltaic cells (the part of the panel that produces electricity) are encapsulated using multiple layers of materials, which have the potential to alter the heat flow into and out of the PV module. The internal operating temperature of the the PV module is influenced by the amount and or the type of materials used in the construction and in some cases, have a major impact on the PV module by reducing its voltage, thereby lowering the output power. Moreover, increases in temperature are implicated in several failure, or degradation, modes of PV modules. For example, as temperatures increase, stresses associated with thermal expansion also increase, thereby increasing the degradation rates by a factor of about two for each 10°C increase in temperature over it's STC ratings.

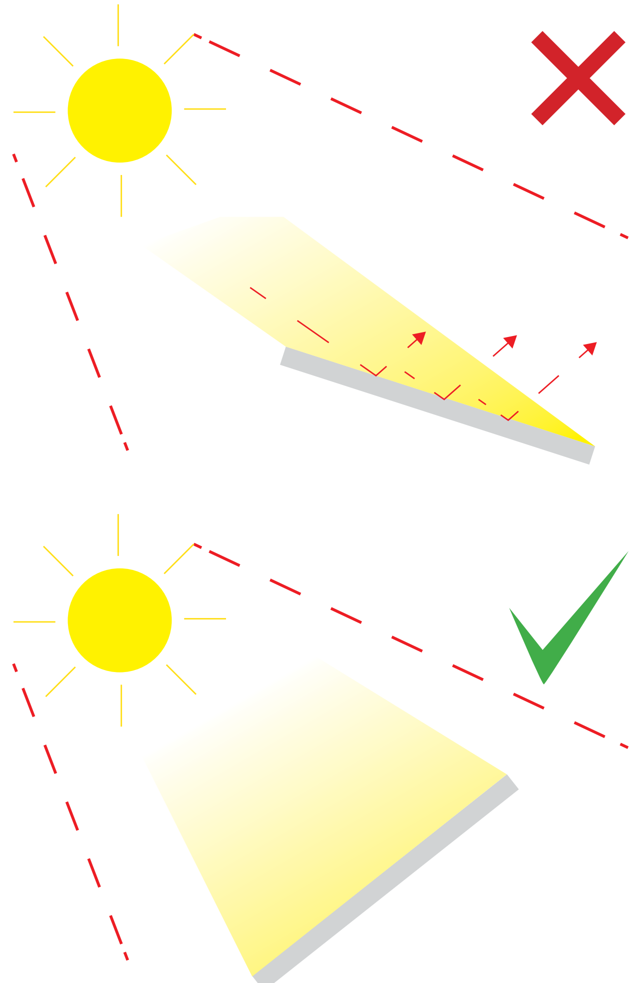
Mounting

When solar panels are exposed to the sun's rays, they will always experience a rise in temperature to a point known as the panel's "operating temperature". Panels are STC rated for a specific amount of power generation in relation to this temperature. The operating temperature of a module is determined by the equilibrium between the heat produced in the PV module, the ambient operating temperature, and the ability of the panel to dissipate heat through its encapsulant materials.

The method of mounting a solar panel plays a significant role in the panel's ability to dissipate heat through one of three mechanisms: conduction, convection and radiation. These heat loss mechanisms depend on the thermal resistance of the module materials, the emission properties of the PV module, and the ambient conditions (particularly wind speed) in which the module is mounted. Mounting the panel away from other hot surfaces (such as a roof) will also aid significantly in cooling the panel.

EXAMPLE

How Angle and Heat Affect a Panel's Power Generation



During a typical Florida day in March, the sun never passes directly overhead. In these conditions, a fixed-angle, 300-watt solar panel system may produce a maximum output of 70 to 80 percent of its peak rating. Flat-mounted systems suffer from their fixed position, as well as from the heat generated inside and under their panels. Excessive heat reduces panel life and hampers the panel's ability to produce power efficiently.

This 300-watt fixed system may yield around 1kWh (90 ampere-hour, or Ah), and slightly more if the system pitches or tilts on a single axis. The limitations of the fixed system often lead users to compensate by increasing the size of the solar panel array in order to produce the desired amount of power.

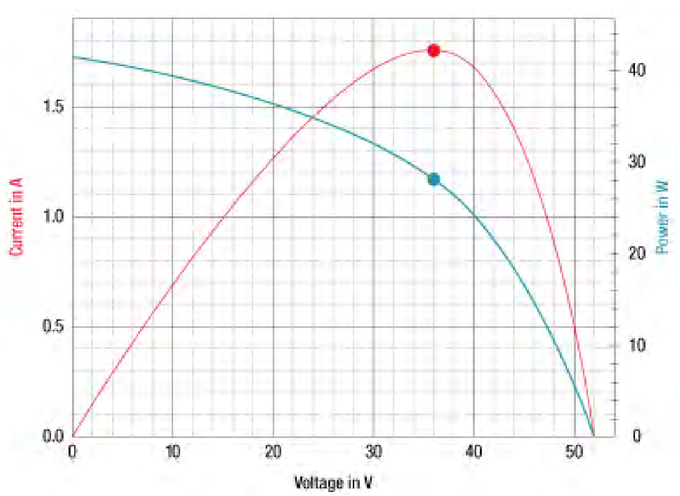
In the summer months in Florida, the sun shifts more directly overhead, and the output gap narrows between a fixed system and an adjustable system. However, adjustable systems have a year-round advantage over larger-wattage, fixed-mount systems. Additionally, a tracking or adjustable array usually has a mounting system that allows the panel to dissipate heat more effectively, thereby cooling the panel and increasing the power output.

MPPT Charge Controls

A charge control should always be used between a solar panel and a battery to ensure that a safe charging voltage is applied to the battery. Maximum Power Point Tracking (MPPT) charge controls serve both the solar panel and the battery by acting as a buffer between them. The MPPT charge control recognizes the solar panel and the battery as individual circuits with completely different characteristics.

In order for charging of a battery to occur, a charging voltage must be greater than that of the battery voltage. The higher voltage on the charger side provides the "push" that enables current to flow into the battery. Charging voltage must also be limited to prevent a battery from over-charging or over-heating.

To understand how MPPT works, let's first consider the operation of a conventional (non-MPPT, such as a series or shunt-type) charge controller. When a conventional controller is used to process solar power for charging a battery, it simply connects the modules directly to the battery. This forces the modules to operate at battery voltage, which is typically not the ideal operating voltage at which the modules are able to produce their maximum power.



These simple charge controllers stop charging a battery when a certain voltage level is reached, and re-initiate charging when the battery voltage drops back below that level.

Pulse Width Modulation (PWM) and MPPT technologies are more sophisticated electronically. Rather than simply connecting the PV module directly to the battery, MPPT charge controls play a key role in maximizing the power generated by a solar panel as it flows into a battery-based DC circuit.

The MPPT charge controller calculates the voltage at which the solar module is able to produce maximum power and automatically adjusts the charging amperage in accordance with the battery's SOC. This allows the solar panels to operate at their rated power output and provide maximum charge current into the battery.

A solar panel's output amperage is determined using the standard formula for power:

$$V \cdot A = P$$
$$A = P \div V$$

When MPPT controls are used in a solar panel system, they allow panels to operate at their rated voltage instead of the battery's voltage, resulting in about a 25-percent increase in power to the battery bank when compared to using less efficient charge controls such as series or shunt-type.

At face value, this equation would indicate that 100 percent of the solar panel's power output is being used to charge the batteries. It should be noted that whenever power is converted from one form to another, power in the circuit is consumed to perform the conversion. The efficiency of the charge control in processing this power varies depending on the manufacturer of the charge control and the type. For the purposes of this discussion and for demonstration purposes only, we will assume that the circuit is 100 percent efficient, but the reader should be aware that the actual efficiencies are between 70 and 96 percent, depending on the control.

EXAMPLE

The Application of MPPT in the Solar Stik System

A standard 12V Solar Stik 100 system is equipped with two 50W solar panels. According to the data plate on one 50W solar panel, it produces 2.8A at 18VDC. Therefore, two panels combined produce 5.6A or 100W of solar power at 18V (the panels on a 12V Stik are connected in parallel, so the Voltage remains the same).

$$P \div V = A$$
$$100W \div 18\ V = A$$
$$= 5.6A \text{ charging current}$$

As discussed, a conventional charge control homogenizes the characteristics of the solar panel and battery into a single circuit, and their individual capabilities are reduced. In this case, the output voltage of the Solar Stik 100 is 18 V, which is significantly higher (6V higher) than the 12V battery. If the Solar Stik 100 is connected to a battery with a SOC of 12V using a conventional charge control, the control would likely reduce the solar panel's operating voltage to a level more harmonious with the battery:

$$V \cdot A = P$$
$$12V \cdot 5.6A = 67W \text{ generated}$$

Simply put, some of the power that is available from the panel would be wasted. In this case, the solar panels generate only 67W of power to charge the battery even though they are rated at 100W of output.

Using MPPT in the Solar Stik System increases the performance of the charging process between the solar panel and the battery. Assume that you have a discharged battery with a SOC of 11 Volts. Since we know it is unreasonable to use 18V for charging, the incoming Voltage is manipulated using MPPT and lowered to about 1V higher than the actual battery voltage. This results in a higher charging current:

P ÷ V = A
100W ÷ 12V = A
= 8.3A charging current

This is an increase in current of about 30 percent. Using MPPT charge controls provides faster and more complete charging of the battery.

EVOLVING **SOLAR PANEL TECHNOLOGIES**

All solar PV cells are made of materials called semi-conductors that absorb photons when sunlight strikes a PV cell. The absorbed photons then knock electrons loose within the PV cells, allowing them to flow, producing a current.

PV cells contain one or more electric field(s) that force the direction of electron flow. Placing metal contacts on the top and bottom of a PV cell harnesses this current to power external appliances, such as a calculator or pool pump. The power, or wattage that a solar cell or a panel of cells can produce is determined by measuring its current and voltage.

For years, companies have sought ways to reduce manufacturing costs associated with traditional PV technologies. This search has resulted in several types of technologies over the course of the industry's evolution.

Silicon solar cells are among the first generation of PV technologies. They are made from a single silicon crystal (mono-crystalline) or cut from a block of silicon comprised of many crystals (multi-crystalline).

Thin-film PV cells are usually classified as either second- or third-generation technologies. Thin-films significantly reduced manufacturing costs compared to the first-generation systems.

Best Performers

First-generation Technologies

First-generation solar panels continue to provide the most power per square foot, as well as excellent durability. Rigid, silicon-based solar panels are widely considered to be the best technology available. However, this high quality corresponds with a higher price, making these panels the most expensive on the market.

Rigid panels are among the best performing panels, but their physical characteristics make them a poor choice for certain applications—especially when portable power is desired.

However, the Solar Stik system design overcomes the physical challenges associated with the first-generation technology. This results in portable power systems that draw from the best available PV technology.

Reducing Costs

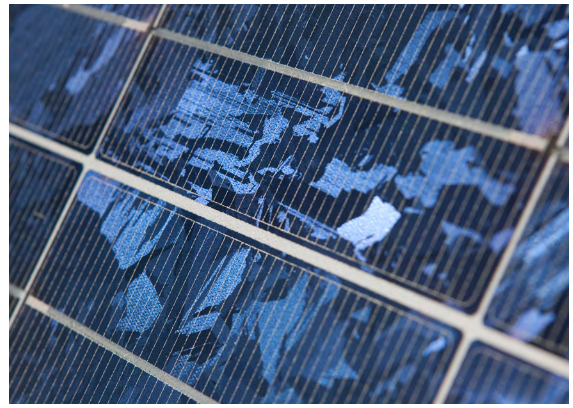
Second-generation Solar Panels

Thin-film solar cells are less expensive to produce than silicon cells because they require fewer materials for construction.

As the name implies, thin-film PV cells lack the thickness of other PV technologies. They are also flexible and lighter. However, they are slightly less efficient than other types of cells, so more surface area is required to generate the same amount of power.

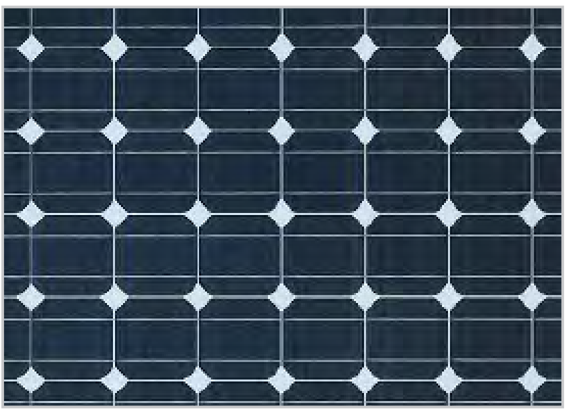
Thin-film panels are often foldable or rollable. This gives them a distinct advantage in terms of storage and transport. For low-power applications that require portability, thin-film panels are an excellent option.

Rigid Solar Panels



Rigid solar panels are typically made of glass panes and aluminum frames. These materials do not degrade significantly over time, making rigid panels the best choice for long-term investment. Rigid panels tend to have the highest efficiencies, making them ideal for applications that require maximum power and a small installation footprint.

In most cases, rigid panel systems are not portable. Their construction limits mobility. Travel and storage is difficult because rigid panels contain breakable glass and often cannot be folded.



Rigid Solar Panel Types and Performance

The two main types of rigid solar panels are monocrystalline, and multi- or poly-crystalline. Rigid panels using this technology average between 15 and 20 percent efficiency, setting the standard for other PV technologies.

While they are similar, monocrystalline panels are slightly more efficient in full sun. However, multicrystalline panels generate slightly higher output during periods of partial shade.

Thin-film Solar Panels

Numerous thin-film solar technologies exist today. The two most common types are amorphous silicon and copper indium gallium selenide (CIGS).

Today's thin-film cells are one percent as thick as the first manufactured silicon solar cells.They are composed of a very thin layer of substance on a substrate. Because it takes very little material to make thin-film cells, this technology generates a lot of interest within the solar power industry.

Amorphous Silicon

Amorphous silicon is the oldest thin-film technology, and arguably the best. When laid on a substrate, amorphous silicon does not require a grid configuration to conduct electricity, allowing it to be used on large areas with ease. However, it does not conduct as well as crystalline silicon because the connections between the silicon atoms are not as consistent. This inconsistency results in interrupted electron flow.

Amorphous silicon cells can achieve an initial efficiency of 10 percent—an excellent value when compared to rigid silicon wafers. Numerous substrate materials can be used with amorphous silicon, making the technology highly adaptable. Polymer plastic is one option for substrate. Because polymer plastic is flexible and able to be folded or rolled, it excels in applications requiring ease of storage or transport.

Copper, Indium, Gallium, Di-selenide (CIGS)

Copper, indium, gallium, and selenide comprise the photoelectric layer of a CIGS solar cell. The principles behind the operation of CIGS cells are the same as those for silicon cells.

With CIGS cells, copper acts to receive electrons in a fashion similar to the positive layer (P-type silicon) of a silicon cell. Selenium provides extra electrons to act in the same way as the negative silicon layer (N-type silicon).

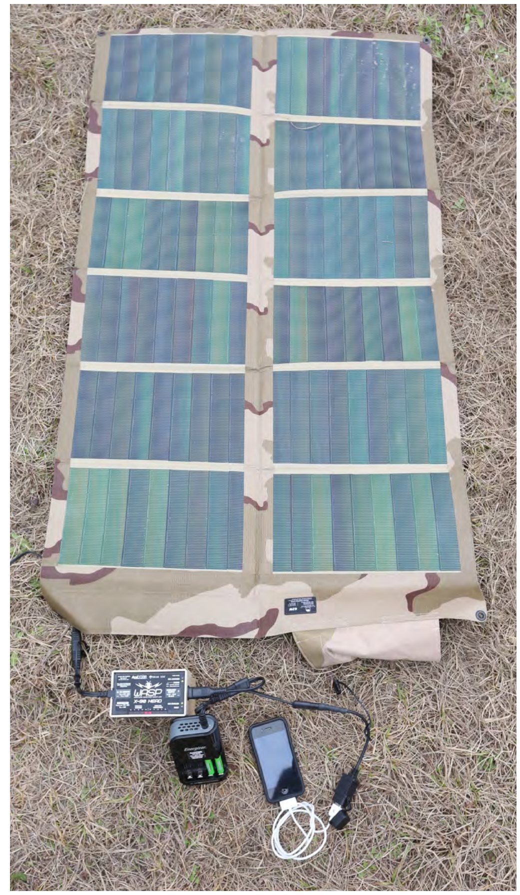
These materials can be placed onto a variety of substrates, including thin flexible steel, glass, and polymers. Flexible steel is the most widely used because of its resistance to the high temperatures needed to lay the PV elements on the backing sheet.

CIGS cells with steel backing offer efficiencies of up to 15 percent; this technology is steadily improving.

Performance Comparison

Amorphous silicon panels are less efficient than crystalline silicon panels, but they also perform better in low-light intensities. This makes amorphous silicon a good choice for environments with interrupted sunlight.

CIGS panels are more efficient than amorphous silicon, but also fare worse in low-light situations.



Flexible Solar Panels and Ground Placement

Often, thin-film arrays are deployed on the ground because of their physical size. Such placement can result in negative effects for PV panels, including

- Indirect sunlight
- High heat
- Panel surface buildup of materials such as dirt, grass, and dust

Operators using thin-film panels laying on the ground should should expect a 40 percent loss of the PV array's rated power output. The easiest way to combat these issues is to deploy extra panels.

OPERATION

Life Expectancy

Much like their rigid-panel cousins, thin-film PV technologies can produce power for many years.

The lifespan of flexible thin-film panels is limited by their physical construction. Many materials used in these panels, such as plastics and fabric, degrade with use and exposure to the elements. In severe environments, a CIGS panel with a heavy-duty plastic or stainless-steel substrate will usually last longer than an amorphous silicon panel of lighter-duty construction with the same power rating. Examine the physical construction of any flexible solar panel to ensure it suits the intended application.

Proper care, maintenance, and the operating environment are also important factors affecting the lifespan of thin-film panels.

Thin-film panels require more care and maintenance than rigid panel technologies. When buying, beware of cheaply produced thin-film panels. The PV technology may be well-crafted, but if the construction is poor, the PV may become unusable quickly.

Operation

Most thin-film panels are designed for single-device applications, like recharging a battery-operated device or powering a blender. Thin-film PV arrays used as generic power sources will likely require connection to a battery. This battery then supplies the power to the appliance(s) via an inverter, converter, or other means.

Connecting Additional Panels

Daisy-chain connectors provide a way to add thin-film panels to an array, allowing operators to scale their systems to meet their power requirements. However, there are limits to the scalability of thin-film PV arrays.

Connecting additional panels does not always provide an increase in power because the small wiring in the construction of many thin-film panels limits the amount of power they can safely conduct. Be sure to consult the literature accompanying your thin-film panel for information adding panels.

Use only the same panel technologies when building an array—especially if using MPPT charge controls. Different panel technologies often operate at different voltages, so using mismatched panels cancels out the benefit of an MPPT charge controller and makes maximum power production unachievable.

For instance, a flexible amorphous silicon panel should not be connected to a circuit that uses rigid monocrystalline panels. While this connection will not result in damage, it will significantly decrease the total power output of the panel array.

Charge Controls

Connecting a thin-film panel directly to a 12VDC battery risks overcharging and damaging the battery. Regulating a panel's charging current with an MPPT control benefits any battery-based solar power system.

Choosing a Thin-Film Technology

When choosing a panel, first consider its intended application and operating environment. Invest in a panel that will withstand environmental challenges such as heat, inclement weather, and rough physical treatment. Solar Stik recommends Global Solar® CIGS, and PowerFilm® amorphous silicon panels.

Ruggedness

Global Solar and PowerFilm panels are much stronger than those of their competitors. PowerFilm panels are made with a plastic substrate. This results in lighter, more flexible panels than those made by Global Solar.

In contrast, Global Solar panels have a stainless steel substrate that makes them heavier and more durable. This provides an advantage in inclement weather. Global Solar panels tend to fare better than PowerFilm panels in wet environments. Both can sustain the abuse that often occurs during military, disaster-relief, and humanitarian missions.

Storage Resistance

Solar Stik Flexi-Panel systems are transported in Pelican® cases, keeping the panels in darkness during transport. Flexi-Panel systems are also commonly stored in vehicle trunks, shipping containers, and even in man-pack kits, all of which expose the panels to high heat. Exposure to high heat in dark environments can have a detrimental impact on CIGS panels.

To counteract this, CIGS panels occasionally require direct exposure to sunlight—a process known as "light soaking"—before they can be used after being stored in dark, hot conditions. Unlike CIGS, amorphous silicon panels can produce their rated power immediately after exposure to high heat and dark conditions. This can be critical in mobile applications that demand power at a moment's notice.

Temperature Dependence

Heat affects the ability of a thin-film panel to produce power. As temperatures rise, CIGS technologies tend to lose power output at a higher rate than amorphous silicon panels.

Efficiency and Surface Area

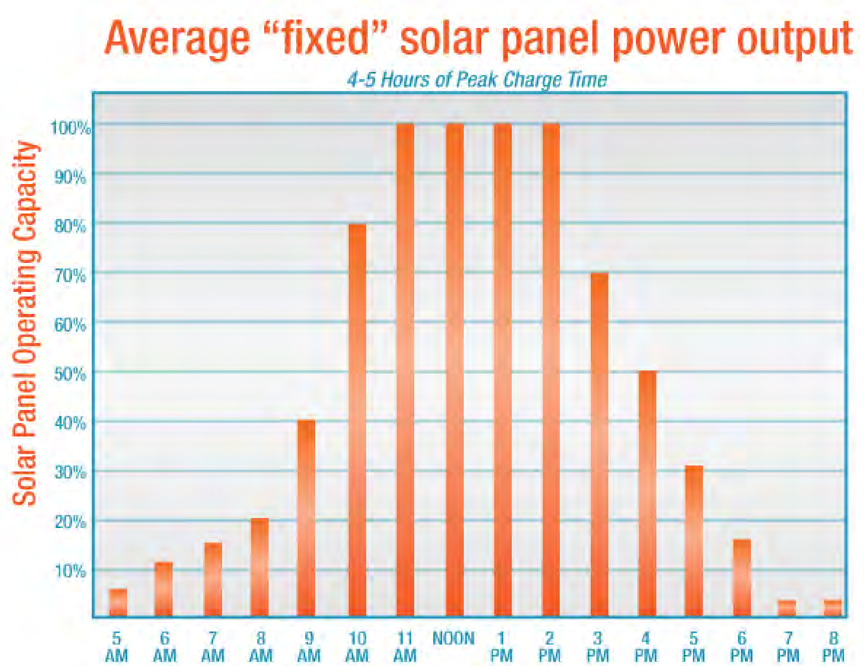
CIGS panels have a higher-rated output per square foot of surface area than amorphous silicon panels, which allows for relatively smaller CIGS panel sizes to achieve an equal amount of power. PowerFilm and Global Solar manufacture their panels at incremental watt values, not by panel size.

All flexible solar panels produce DC power and are usually available in common voltages such as 12- or 24-volts DC.

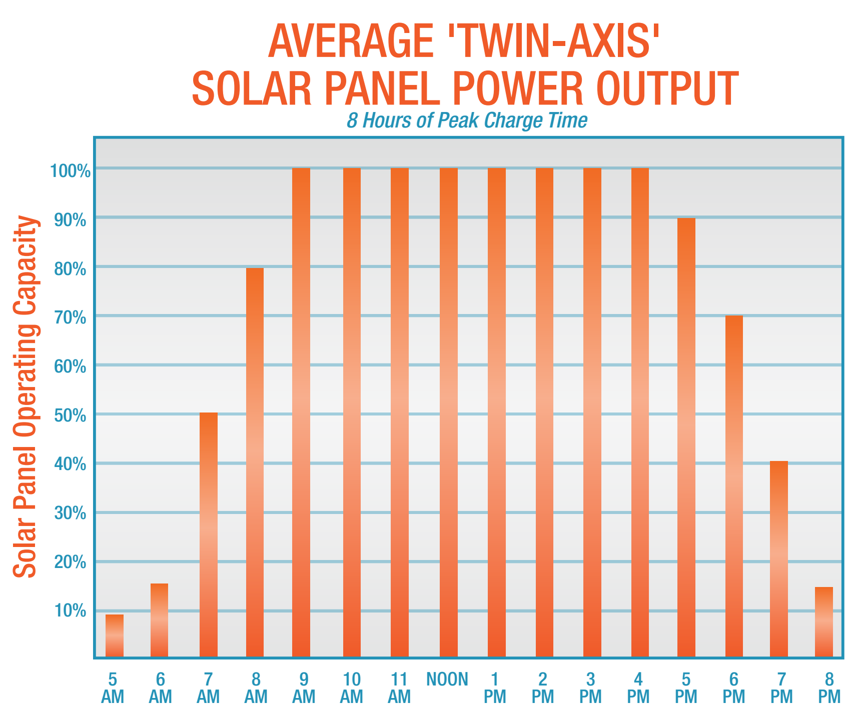
Stationary versus Adjustable Solar Panels

The following graphs demonstrate the differences in power production between a flat or fixed solar array and one that is adjustable on two axes of rotation.

The Solar Stik design features a mechanical arm that allows panel adjustment to maximize solar exposure. A Solar Stik also suspends the panels, allowing good air circulation that keeps the panels cooler and operating at maximum power output.



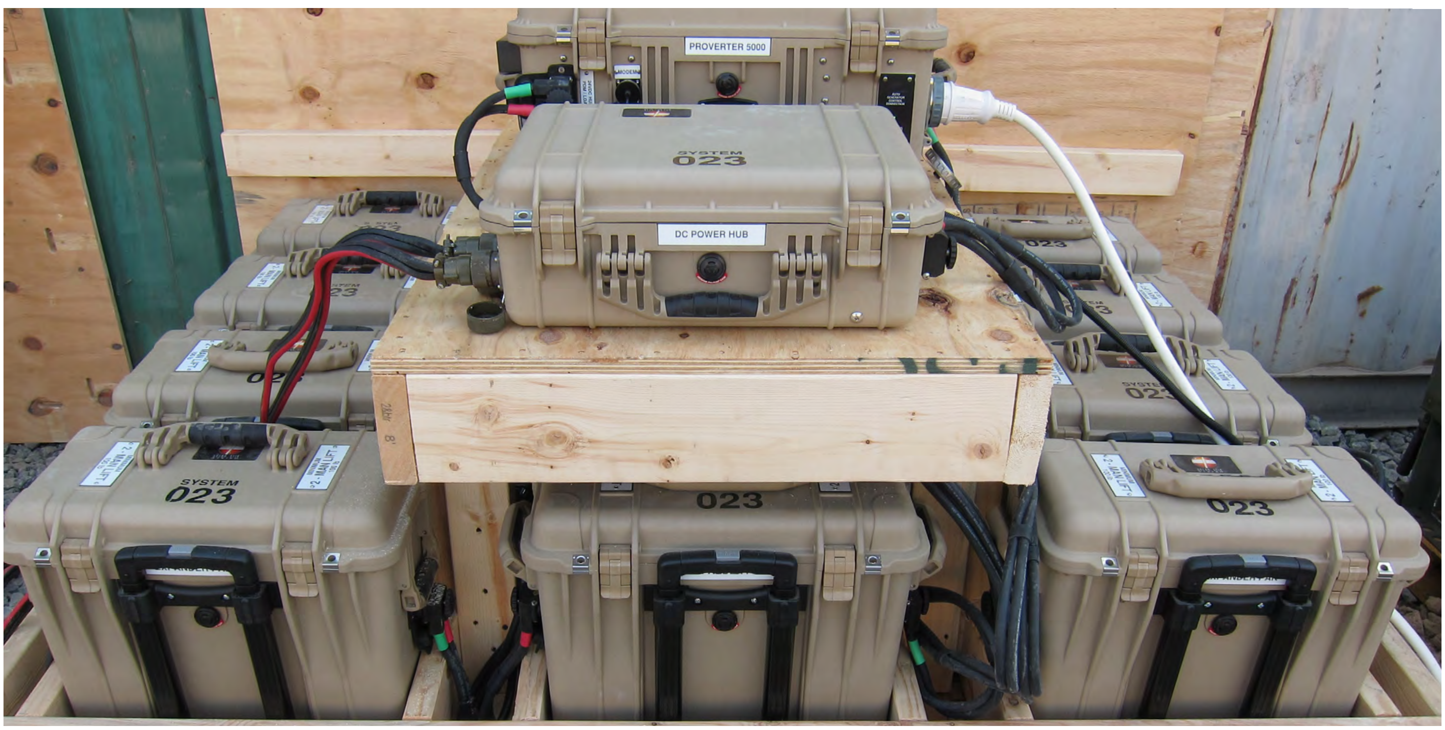
4-5
HOURS
Peak Charge Time



8
HOURS
Peak Charge Time

SOLAR STIK®

STIKOPEDIA



MODULE FIVE

Battery School

LEAD-ACID **BATTERIES**

The battery is the heart of any DC-based electrical system. While the Solar Stik System is engineered to work with nearly any 12V battery technology, it will usually operate best with lead-acid batteries. Nearly all Solar Stik Power Paks utilize lead-acid battery technology

The battery for any Solar Stik System requires proper use and care, so it is important for the operator to fully understand the particular battery in their Pak.

A Brief History of Lead-acid Batteries

Lead-acid is the oldest rechargeable battery technology in existence. Invented by the French physicist Gaston Planté in 1859, lead-acid was the first rechargeable battery to be used in commercial applications. One hundred fifty years later, we still have no real cost-effective alternatives for cars, boats, RVs, wheelchairs, scooters, golf carts, and UPS systems.

The lead-acid battery is still the most widely used 12V energy storage device. A lead-acid battery is an electrical storage device that uses a chemical reaction to store and release energy. It uses a combination of lead plates and an electrolyte to convert electrical energy into potential chemical energy and back again.

There are many newer battery technologies available in the marketplace. However, lead-acid technologies are the most understood and are widely accepted as the standard by which all other batteries are measured. Newer technologies often have operational constraints, including maximum and minimum operating temperatures and special charging requirements that make them less versatile and useful for the average consumer in everyday applications.

2 Basic Lead-acid Types

Engine Starting: Starter batteries are made for maximum power output and are usually rated in cold-cranking amps, or CCA. The battery manufacturer achieves this maximum, short-burst output by combining many thinner lead plates to obtain larger surface area for maximum conductivity. Typical applications are cars and motorcycles.

Deep-Cycle: A deep-cycle battery is designed for maximum energy storage capacity and high cycle count, or long life, and is rated in amp-hours (Ah). These attributes are achieved by installing fewer, and thicker lead plates with limited surface area. Typical applications for deep-cycle batteries are boats, golf carts, wheelchairs, solar applications, RVs, and uninterrupted power supplies (UPS).

Lead-acid Battery Components

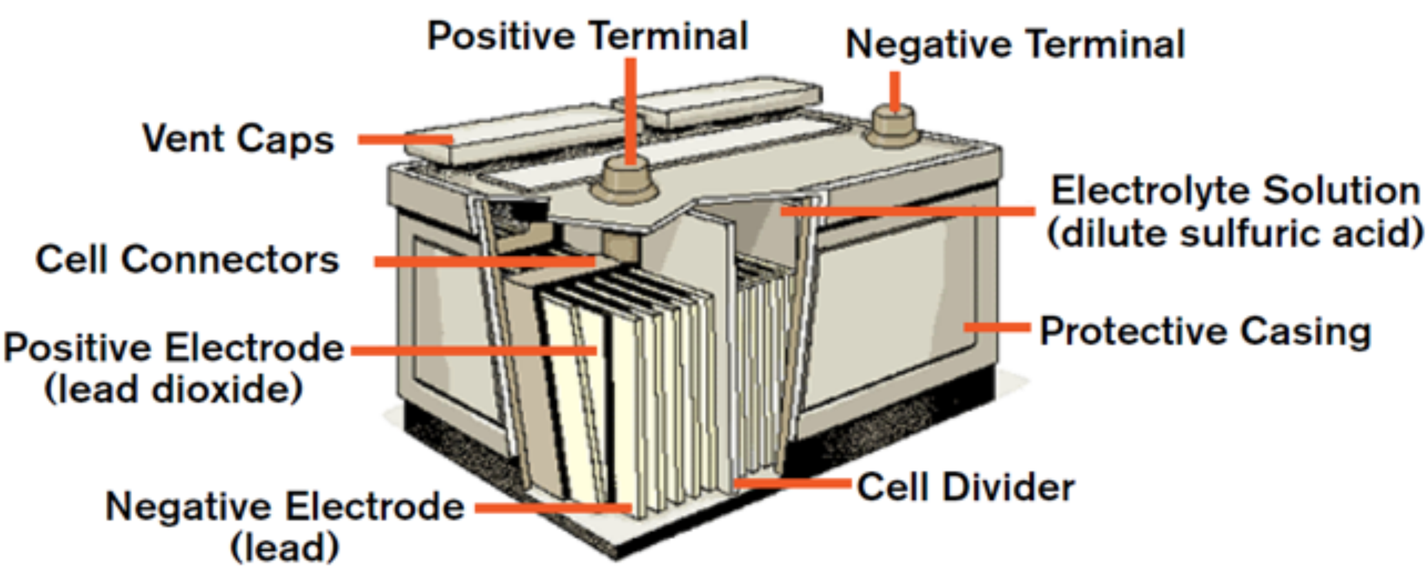
Lead-acid Batteries are Commonly Made of Five Basic Components:

- A resilient plastic container
- Positive and negative internal plates made of lead.
- Plate separators made of porous synthetic material.
- Electrolyte, or a diluted solution of sulfuric acid and water, known as battery acid
- Battery terminals–the connection point between the battery and the load that requires the battery's power

Battery cells are the most basic individual components of a battery. A cell is simply a container in which electrolyte and lead plates can interact. The electrolyte is usually a solution made up of 35 percent sulfuric acid and 65 percent water. The lead plates are usually treated with lead oxide and powdered sulfates to give them their positive and negative properties.

Individual cells are then placed together in a single case and connected in series. Since each cell produces a certain voltage, also known as electromotive force, they can be configured to provide a cumulative voltage necessary to perform certain functions (such as 12V, 24V, or even 48V).

The voltage rating of a lead-acid battery is directly related to the number of cells that have been wired in series. A standard lead-acid battery cell normally has a voltage of around 2V, so a 12V battery usually consists of 6 cells wired in series (2V · 6 cells = 12V).



Lead-acid Battery Configurations

Lead-acid batteries come in several different configurations.

Types of Lead-acid Batteries

Flooded

The oldest of the lead-acid battery types, flooded-cell batteries, can be either the sealed or the open variety. In both types, the electrolyte evaporates due to charging, age, or ambient heat.

Sealed flooded cells

- Frequently found as starter batteries in cars
- Electrolyte cannot be replenished
- Battery has to be replaced when enough of the electrolyte has evaporated

Open flooded cells

- Also called deep-cycle
- Usually have removable caps that allow you to replace any evaporated electrolyte
- Battery life is extended due to replaceable electrolyte

Sealed Lead-acid

In the mid 1970s, a “maintenance-free” lead-acid battery was developed.

- Can operate in any position
- Liquid electrolyte is gelled into moistened lead plate-separators
- Gelled electrolyte allows the case to be sealed
- Safety valves allow venting during charge, discharge, and atmospheric pressure changes

Driven by different market needs, two lead-acid systems emerged: The small sealed lead-acid (SLA), also known under the brand name of Gel-cell, and the larger valve-regulated lead-acid (VRLA). Both batteries are similar. (Incidentally, engineers sometimes argue that the phrase “sealed lead-acid” is a misnomer, because no rechargeable battery can be totally sealed.

VRLA batteries remain under constant pressure of 1-4 psi. This pressure helps the recombination process during charging when more than 99 percent of the hydrogen and oxygen generated are turned back into water.

Unlike the flooded lead-acid battery, both SLA and VRLA are designed with a low over-voltage potential, which prohibits the battery from reaching its gas-generating potential during charge. This safeguard prevents excess charging, which would cause gassing and electrolyte depletion.

Gel batteries feature an electrolyte that has been immobilized using an agent like fumed silica. Consequently, these batteries can never be charged to their full potential.

Absorbed Glass Mat (AGM)

AGM is a newer type of sealed lead-acid with several distinctions from traditional, sealed lead-acids

- AGM uses absorbed glass mats between the plates. It is sealed and maintenance-free, and the plates are rigidly mounted to withstand extensive shock and vibration.
- AGM features a thin fiberglass felt that holds the electrolyte in place like a sponge.
- Nearly all AGM batteries are recombinant, meaning they can recombine 99 percent of the oxygen and hydrogen, resulting in almost zero water loss.
- Charging voltages are the same as for other lead-acid batteries. Even under severe overcharge conditions, hydrogen emission is below the 4 percent specified for aircraft and enclosed spaces. The low self-discharge of 1-3 percent per month allows long storage before recharging.
- AGM generally costs twice as much as a flooded battery of the same capacity.
- AGM is usualy found in applications where high performance is demanded.

Like other VRLA batteries, the AGM lead-acid battery remains under constant pressure of 1-4 psi. As previously noted, this pressure helps the recombination process during charging, under which more than 99 percent of the hydrogen and oxygen generated during charging are turned back into water.

Neither AGM nor other sealed lead-acid batteries will leak if inverted, pierced, or otherwise compromised. These batteries will continue to operate even under water.

PHYSICAL AND **OPERATIONAL PROPERTIES**

Lead-acid Battery Plates

The secret of any battery's runtime lies in the battery's plate capacity.

- The service life of a lead-acid battery can be measured by the thickness of the positive plates.
- The plates of automotive starter batteries are about 0.040in (1mm) thick.
- Forklift batteries may have plates that exceed 0.250in (6mm).
- A typical golf cart battery has plates that are between 0.07-0.11in (1.8- 2.8mm) thick.
- The thicker the plates, the longer the life will be and the more energy storage you can expect.
- During charging and discharging, the lead on the plates gets gradually eaten away and the sediment falls to the bottom.

Credit: Steve Rainwater

The weight of a battery is another good indicator of the lead content and the life expectancy. Generally speaking, the heavier the battery, the more lead it contains and the longer it will last.

Most industrial flooded deep-cycle batteries use lead-antimony plates. Antimony is a metal that stiffens the lead plate and helps prevent battery failure due to structural failure of a plate. This improves the plate's life but increases gassing and water loss. Antimony is not necessary in AGM batteries due to the rigid construction of the overall battery.

Battery storage capacity and deep-cycling are less important in automotive applications because the battery is being recharged while driving. If continuously cycled, the comparatively thin lead plates of a starter-type battery would wear down rather quickly.

How the Chemical Reaction in a Battery Works

When the positive and negative lead plates are submerged in the electrolyte, a chemical reaction occurs. This reaction causes electrons to flow between the lead plates. The amount of push or force of the electrons moving between the plates is known as the voltage.

Credit: Kate Ter Haar

The process can be summarized as:

A reversible transfer of sulfate between the water and the lead plates during charging and discharging.

As the battery is discharged, sulfate in solution combines chemically with the lead plates of the battery to form lead sulfate. As the plates accumulate this sulfate, the electrolyte solution becomes more like water and less like sulfuric acid.

The reverse occurs as the battery is charged. As charging current flows into the battery, the battery plates revert back to their original condition and the electrolyte reverts back to its original sulfuric acid content.

Specific Gravity of a Battery's Electrolyte

Specific gravity is a measure of the health of the electrolyte in a lead-acid battery.


Credit: Scott Robinson

Specific gravity of the electrolyte can be defined as:

A measure of the density of the liquid electrolyte compared to the density of water at a specific temperature and pressure.

During the battery discharge process, the electrolyte transfers its sulfur content to the lead plates. As the electrolyte loses sulfer, its specific gravity gets “lighter” or closer to that of water, indicating that the battery has been discharged.

Because the specific gravity of the electrolyte is measurable, it can be used to determine the state of a battery's charge and health.

Battery Voltage

The voltage of a battery is a direct indication of its state of charge. It indicates the amount of electromotive force (or the amount of push) that moves electrons from positive to negative fields.

Voltage is a function of the specific gravity of the electrolyte at the place in the battery where the chemical reaction occurs. This chemical reaction takes place inside the pores of the active material on the lead plates.

If the battery has just been charged, the electrolyte in the pores of the battery's lead plates is very rich in sulfuric acid. As a result, the battery's voltage will be high, perhaps as much as 13 to 14 volts. As the battery rests following a charge, its voltage slowly drops and then levels off as the electrolyte stabilizes its chemical state between the plates.

A similar change in battery voltage occurs during discharge. While a fully charged battery may read 12.68 volts, the voltage will drop and then stabilize at a somewhat lower value as a load is applied.

The change in voltage occurs even though the state of charge of the battery has not significantly changed. This is due to the local electrolyte in the pores of the plates becoming less rich in sulfur as the battery supplies current. As the battery discharges, electrolyte more like sulfuric acid enters the pores while electrolyte more like water exits the pores.

As discharge continues, the electrolyte in the pores eventually stabilizes at a specific gravity somewhat lower than the average value in the battery, producing the slightly lower battery voltage.

Battery Capacity and Cold-cranking Amps (CCA)

The operational characteristics of the lead-acid battery can be explained best by the terms capacity and cold-cranking amps (CCA).

Capacity

- Amount of energy a battery can store
- Usually given in amp-hours (Ah),or the amount of current, measured in amps, that the battery can provide over a period of one hour before rendering the battery discharged

Cold-cranking Amps (CCA)

- Amount of energy a battery can deliver in short bursts
- Maximum amount of current (amps) that a battery can deliver at 0°F for 30 seconds without dropping below 7.2 volts

A high CCA battery rating is good, especially in cold weather. Starter batteries are often rated in CCA and are designed to deliver a short-duration burst of power, such as that required to start a vehicle.

20-hour Rate

For typical 12-volt batteries, the amp-hour rating (capacity) is determined at what is called a “20-hour rate”. This describes the total amount of current that can be consumed from the battery before causing the battery’s voltage to drop to 10.50V over the course of 20 hours.

Credit: Arjan Richter

For example, a 105 amp-hour (Ah) battery can deliver 5.25A for 20 hours before the battery voltage drops to 10.50V, at which point the battery is considered depleted. The same battery will also deliver approximately 10.50A for 10 hours, and so on.

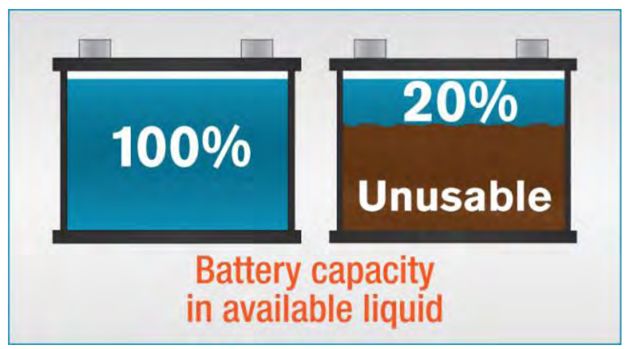
The formulas for determining the power available in a lead-acid battery are not concrete. The actual amp-hours available from a particular battery will be somewhat higher if less current is delivered over a longer period, and somewhat lower if more current is delivered over a shorter period. This is due to the slightly higher energy loss as a battery is discharged more quickly.

Capacity versus CCA

Age and environmental conditions can effect the capacity and the CCA.

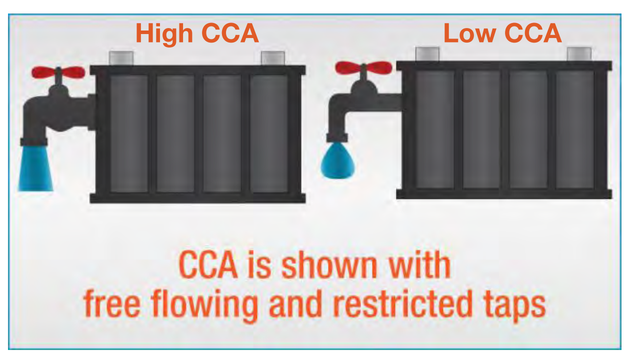
Capacity

The illustration to the right shows two fully charged lead-acid batteries, one with a high capacity (left) and one that has aged (right). The build up of visible “rock content” (crystalline formation, also called sulfation or memory) due to aging robs the battery of usable capacity, although the battery may still provide good cranking power.



Cold-cranking Amps (CCA)

The illustration to the right shows a battery with high (left) and low CCA (right) by simulating free-flowing and restricted taps.



Operational Variance and Degradation

The electrical characteristics of a battery are based on chemical reactions, and chemical reactions rates depend on many factors. Therefore, there is always some variation in the value assigned to a particular characteristic such as amp-hours.

If you are trying to determine the exact amount of power available from a particular battery, the number will always be a little bit different than what you calculate, as batteries are affected by numerous external and changing factors:

- Temperature
- Rate of Discharge
- Charging Efficiency
- Battery Health
- Battery Age

If a battery is rated at a capacity of 105Ah, by definition it could theoretically provide 100 amps over a period of 1 hour. However, it is unreasonable to expect the same results after, say, 50 discharge/recharge cycles. As the number of battery cycles increases, you will notice a decrease in the amount of power that is available, even though you may have fully recharged the battery to 13 volts during every cycle.

Determining Battery Health

As a battery ages, capacity and CCA will not degrade at the same rate.

- CCA tends to stay high through most of the battery's life, but it drops quickly towards the end. If you drive a car, you've probably experienced this when, near the end of the battery's life, suddenly the battery won't start the car in the morning.
- Capacity decreases gradually. A new battery is designed to deliver 100 percent of its rated capacity. As the battery ages, the capacity steadily drops and it should be replaced when its ability to store power falls below 70 percent of its original rating.

The overall health of a battery is most directly related to its capacity, **not its CCA**. As noted before, the CCA remains within the optimal range for most of a battery's life, so performance and health declines will be most notable in the loss of capacity.

Typical Problems of Lead-acid Batteries

The conversion efficiency of a battery denotes how efficiently it converts an electrical charge into chemical energy and then back again. A higher efficiency (expressed as a percentage) means that less energy is converted into heat (heat is lost energy), and that the battery can be discharged faster without overheating–assuming all other factors are equal.

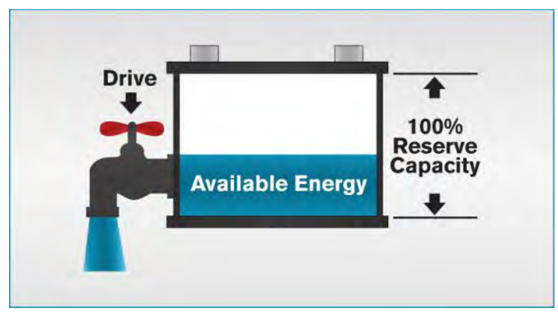
Credit: Dan Machold

The lower the internal resistance of a battery, the better its conversion efficiency will be. This is another reason to avoid the build up of "rock content", which increases the resistance of the battery similar to the build-up of solutes within a pipe would decrease the flow rate of water through the plumbing.

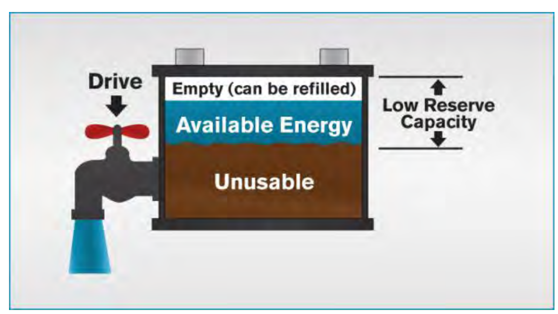
Storage batteries are not 100 percent efficient at converting charging amp-hours back into stored amp-hours. One of the main reasons why lead-acid batteries dominate the energy storage market is that the conversion efficiency of lead-acid cells is 85-95 percent. Generally speaking, this is often much higher than other types of rechargeable battery technologies.

However, even at 90 percent efficiency it will take approximately 110Ah of charge to replace 100Ah of consumed capacity from a lead-acid battery.

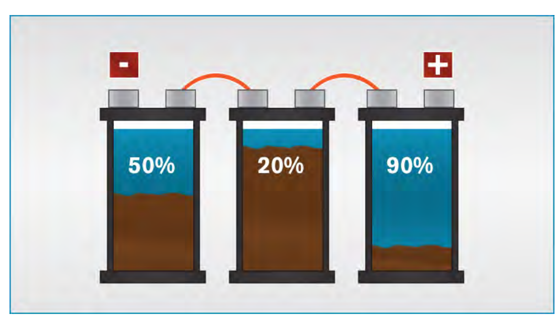
Low charge results in a weak drive of current output.



Low capacity will likely have good conductivity and strong torque in short bursts. The voltage will be fine and everything will appear normal except that it has a short runtime. Knowing the capacity of an aging, deep-cycle battery is very important because it is the best indication of when a battery should be replaced.



Mismatched batteries Different batteries, and especially different types of batteries, age at different rates. Like the links of a chain, the battery with the lowest capacity will determine the runtime. Do not use different types of batteries together in a bank.



Sulfation (or sulphation) starts when the electrolyte's specific gravity falls below 1.225, or when voltage measures less than 12.4V (in a 12V battery or 6.2V for a 6V battery). Sulfation is a salt that forms on the battery plate surface that hardens the battery plates. If left long enough, it will reduce and eventually block chemical reaction between the lead plate and the electrolyte. It diminishes the ability of the battery to generate its rated voltage and amperage.

"Sulfation is the main reason a significant percentage of lead-acid batteries don't reach their intended life span."

Sulfation is the main reason a significant percentage of lead-acid batteries don't reach their intended life span.

Equalization is a process that is sometimes used to decrease sulfation on the lead plates. Because sulfation acts as a barrier on the lead plates, it inhibits their ability to store and dispense energy. To help reverse sulfation, an equalizing charge is applied to raise the battery voltage above its rated voltage for several hours. This process reduces sulfation, reversing the aging process of the battery.

Although beneficial in reversing sulfation, the side effects of equalization are elevated temperature, gassing, and loss of electrolyte if the equalizing charge is not administered correctly. The equalization step should be a last resort to break up the sulfate layers. Because the process will likely cause the battery electrolyte to boil and produce potentially explosive gas, it should only be done with strict supervision of the battery and with the proper precautions.

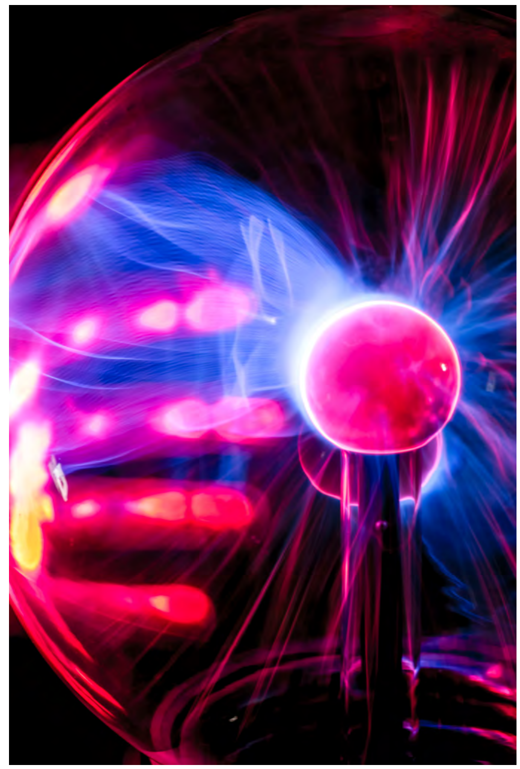
Note: A sealed battery should never be equalized.

Gassing occurs when you attempt to charge a battery faster than it can absorb the energy. This excess energy is turned into heat, which then causes the electrolyte to boil and evaporate. The evaporated electrolyte can be replenished in batteries with removable caps which are present on most flooded deep-cycle batteries. However, most car batteries are sealed and thus need to be replaced when their electrolyte evaporates.

Since AGM and gel cells (SLA and VRLA) are always sealed, it is very important to ensure they are not overcharged. The only way to ensure this is to use a temperature-compensated charging system. Such chargers use a temperature probe on the battery to ensure that it does not overheat. If a charger has temperature compensation, it will detect and react to the battery temperature accordingly. As the battery heats up due to a fast (high-current) recharge, the charging current is reduced to prevent thermal runaway.

Thermal runaway, is a very dangerous condition that can occur if batteries are charged too fast and become too hot. The increased heat accelerates the chemical reactions in the battery, which in turn generates even more heat. It is a snowball effect. If the heat gets out of control, the electrolyte boils and releases large amounts of hydrogen and oxygen gas, both of which are highly explosive. The battery case can bulge and explode as the battery melts from the inside out.

The danger posed by local accumulation of hydrogen gas is so serious that many regulatory agencies require that batteries are installed in well-ventilated areas.



Credit: TC Morgan

Self-discharge is a measure of how much batteries discharge on their own. The self-discharge rate is governed by the construction of the battery and the properties of the components used inside the cell, such as the alloy of the lead or the sulfuric acid concentrations of the electrolyte.

For instance, flooded cells typically use lead/antimony alloy, which stiffens the plates and increases their mechanical strength. However, antimony also increases the self-discharge rate of the battery between 8 to 40 percent per month. This is why flooded lead-acid batteries should either be used often or left on a trickle-charger.

The lead found in gel (SLA and VRLA) or AGM batteries does not require a lot of mechanical strength, because it is immobilized by the gel or fiberglass. Thus it is typically alloyed with calcium (which is less rigid), and has lower gassing and self-discharge rates. The self-discharge rate of gel and AGM batteries is generally only 2 to 10 percent per month and thus these batteries need less maintenance and are better able to be stored long term than flooded lead-acid batteries.

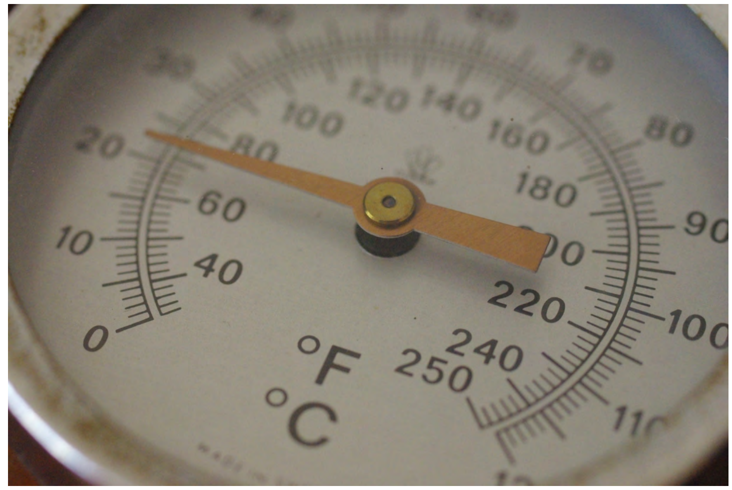
Effects of Temperature

Lead-acid batteries are reasonably forgiving of temperature extremes, as we witness daily with the performance of automotive batteries in diverse climates. Part of this tolerance is credited to the “sluggishness” of the lead-acid system.

Some battery types, like AGM, even permit freezing and low-level charging. Others, like the flooded cell, will sustain damage and deliver reduced capacity and a short service life if they are frozen.

The optimum operating temperature for the lead-acid battery is 25°C (77°F). Generally speaking, every 8°C (15°F) rise in average temperature will cut the battery life in half. For example, a VRLA that would last for 10 years at 25°C (77°F) will only be good for 5 years if operated at 33°C (92°F) and will only last a little more than one year at a desert temperature of 42°C (108°F).

Excessive heat degrades lead-acid batteries over time. The warmer the cells, the shorter the life expectancy. Elevated temperatures cannot always be prevented, especially during fast charging, but efforts must be made to keep this time brief. While 45°C (113°F) is acceptable for brief periods, at 50°C (122°F) and above the battery starts to suffer. Also note that the cells inside the battery case are always a few degrees warmer than the outer housing.



Credit: Ged Carroll

CHARGING LEAD-ACID BATTERIES

Voltage, Current, and Time - The Parameters for Recharging

Charging voltage: A lead-acid battery is charged by applying a voltage across its positive and negative terminals that is higher than the voltage it already has across them. The greater the difference between the applied voltage and the battery voltage, the greater the charging current that will flow into the battery and the quicker the battery will be charged.

Charging current: All batteries have a maximum current at which they can be charged safely. High charging current means less time is necessary to complete the recharging process. However, charging at the maximum allowable, or higher current, can also shorten battery life. Cases of extreme over-current could result in a hazardous condition due to battery overheating and thermal runaway.

Charging time: The charge time of a sealed lead-acid battery is normally 12 to 16 hours, and up to 36 hours for larger capacity batteries. With higher charge currents and multi-stage charge methods, the charge time can be reduced to 10 hours or less. It takes 3 to 5 times as long to recharge a lead-acid battery to the same level as it does to discharge it.

Common Types of Battery Charging Devices

Battery chargers: Most garage and consumer (automotive) battery chargers are bulk charge only and have little, if any, voltage regulation. They are fine for a quick boost to low batteries but should not be left connected for long periods of time. Damage to the battery can occur when a battery is left connected to this type of charger for extended amounts of time.

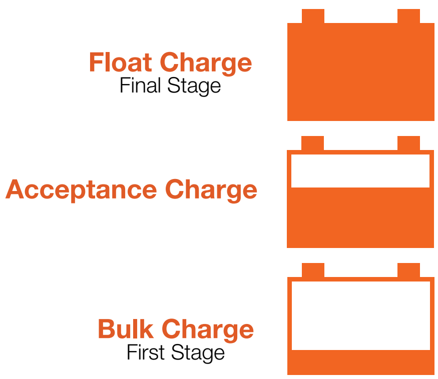
Regulated chargers: A voltage-regulated charge control is designed to supply constantly regulated voltage to batteries. If these are set to the correct voltages for the batteries, they will keep the batteries charged without damage. These are sometimes called taper chargers.

Battery charge controllers: These are regulators that go between a charging source, such as solar panels, and the storage batteries. Regulators for solar systems are designed to keep the batteries charged to peak voltage without overcharging.

Best Charge Method for Deep-cycle Lead-acid Batteries

Whatever the charging source–grid (AC) connection, solar panel, or even an automotive alternator - a multi-stage, or three-stage, charging process is the best method to recharge a lead-acid battery. This method takes all three parameters (current, voltage, and time) and sequentially applies each one at specific rates and duration.

The three stages in multi-stage charging:



Bulk charge

The charging device applies a constant current charge, raising the cell voltage to a preset level. The charge rate depends on the difference between the charging voltage and the battery voltage. This first stage of charging keeps the voltage difference between the charger and battery constant so that as the battery voltage rises, the charging voltage rises and the charging current remains constant.

This stage typically takes the battery to about three-quarters charged, and at a rate that usually does not exceed 25 percent of the battery's amp-hour capacity.

Acceptance, or absorption, charge

In this stage, the charge current is gradually reduced as the cell becomes saturated. Charging current is reduced to about half of the bulk charge rate. Since battery charging is an electrochemical process that (particularly in the case of deep-cycle batteries) has a very long reaction time, the charging voltage in this stage is reduced for a few hours to enable the charge that is now concentrated in and around the plates to become homogeneously distributed through the entire battery.

The acceptance stage is typically maintained for several hours.

Float Charge

The final stage is the float charge, which compensates for the self-discharge of the battery. Following the acceptance stage, the charging voltage drops further to a level that eventually counterbalances the battery's internal losses. Depending on ambient temperature and battery type, float charge will usually be between 13.2V and 13.3V (AGM and gel batteries) or 13.6V to 13.8V (flooded-cell batteries).

Batteries can usually be left in float stage indefinitely. During the float stage, a battery will typically be 95 to 97 percent charged.

Temperature-compensated charging

To improve charge performance of lead-acid batteries at colder temperatures and to avoid thermal runaway during hot spells, controlling the charging voltage is important. Implementing such a measure can prolong battery life by up to 15 percent.

Higher temperatures require slightly lower charging voltage, while lower temperatures require slightly higher charging voltage. Three-stage chargers that have a battery temperature sensor are excellent for batteries that are exposed to large fluctuations in temperature.

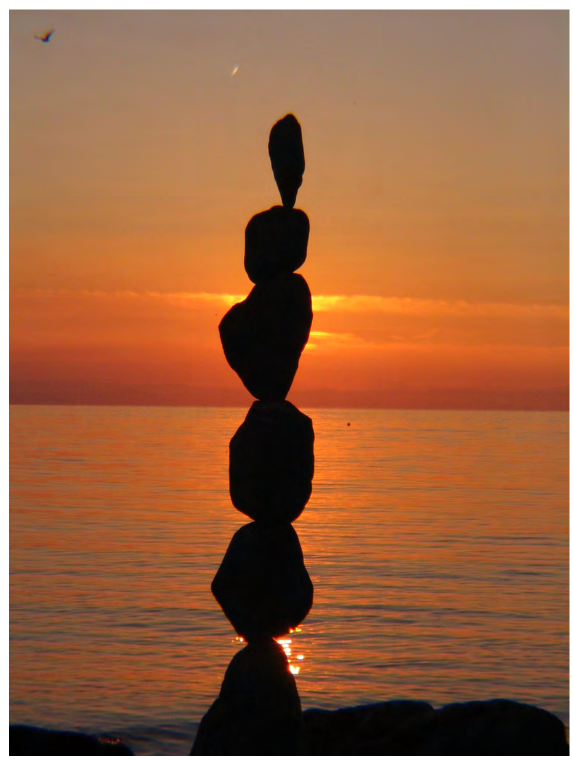
Balancing Care and Operation

As covered earlier, individual lead-acid cells are wired in series to achieve a desired voltage (as in a 12V battery).

Correct settings of the voltage limits, or maximum voltage, for the individual cells is critical. In a lead-acid cell, the range is usually from 2.30V to 2.45V.

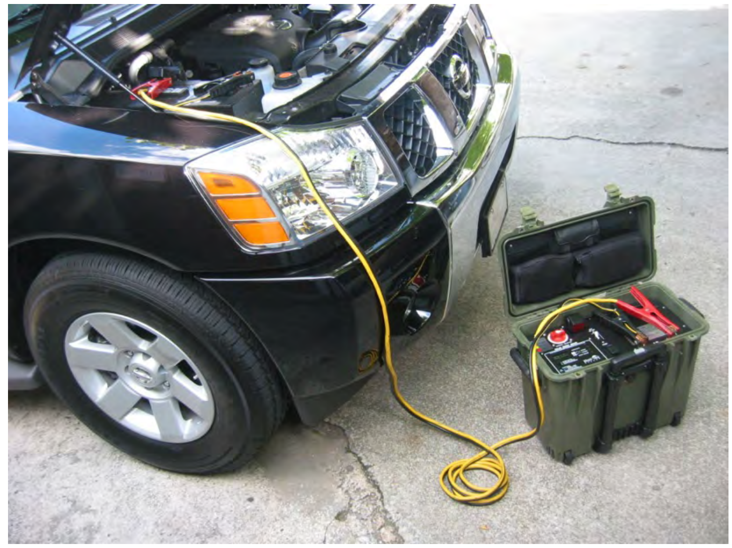
Setting the voltage limit is a compromise. On one hand, the battery needs to be fully charged to provide maximum capacity and to avoid sulfation on the negative plate. On the other hand, a continually over saturated (over charged) condition would cause corrosion on the positive plate. Over saturation also promotes gassing, which results in venting and loss of electrolyte.
The battery should not remain at peak voltage for too long; the maximum recommended time is 48 hours.

When reaching full charge, the voltage must be lowered to maintain the individual battery cells at between 2.25V and 2.27V. (Manufacturers of large lead-acid batteries recommend a float charge of 2.25V at 25°C per cell.)



Credit: Heiko Brinkmann

Car batteries and valve-regulated lead-acid (VRLA) batteries are typically charged to between 2.26V and 2.36V. At 2.37V, most lead-acid batteries start to gas, causing loss of electrolyte and increased temperatures. The exceptions are small sealed lead-acid batteries (SLA), which can be charged to 2.50V per cell without any adverse side effects.



Large VRLA batteries are often charged with a float-charge current to 2.25V per cell. A full charge may take several days. Note that the current in float-charge mode gradually increases as the battery ages. The reasons for this are typically, electrical cell leakages and a reduction in the battery's chemical efficiency.

Aging affects each battery cell differently. Since the cells are connected in series, it is virtually impossible to control the individual cell voltages during charging. Even if the correct overall voltage is applied, a weak cell will generate its own voltage level and in turn affect the battery as a whole. To slow the aging process, lead-acid batteries must always be stored in a charged state.

A topping-off charge should be applied every six months to prevent the voltage from dropping below 2.10V per cell on an SLA. Prolonged storage below the critical voltage causes sulfation, a condition that is difficult to reverse.

Using a Lead-acid Battery while Charging

An external load can be connected to a lead-acid battery while in float-charge mode. In such a case, the battery acts as a buffer. The Solar Stik System works in just this way. During off-peak periods, the batteries get fully charged. During peak power demand, the load exceeds the net supply provided by the solar array and the battery makes up the difference, providing extra energy. A car battery works in a similar way.

When configuring a battery as a buffer, make certain that the battery has the opportunity to charge fully between loads. The net charge of the battery must be greater than what the load draws from the battery.

Battery Testing

Battery testing can be done in several ways, and the method often is chosen according to the type of battery and the tools available.
The most popular methods include:

- Measurement of battery voltage
- Measuring the specific gravity of the electrolyte
- Load testing

State of Charge	12 Volt	6 Volt	Specific Gravity
100%	12.9	6.4	1.265
75%	12.4	6.2	1.225
50%	11.9	6.0	1.190
25%	11.4	5.8	1.155
Discharged	10.5	5.5	1.120

Battery voltage, or state-of-charge, of a lead-acid battery can be estimated by measuring the open (no load) battery terminal voltage using a digital voltmeter. Prior to measuring, the battery must have rested for 4 to 8 hours after charge or discharge and resided at a steady room temperature. With these conditions met, voltage measurements provide an amazingly accurate state-of-charge for lead-acid batteries.

Specific gravity can be measured in wet-cell batteries with removable caps that provide access to the electrolyte. To measure specific gravity, you must use a tool called a temperature-compensating hydrometer, which can normally be purchased at an auto parts store or tool supply.

Load testing removes and measures the amps from a battery, similar to what happens when you start the engine of a car. Some battery companies label their battery with the amp load for testing. This number is usually about half of the CCA rating. A battery rated at 500 CCA would therefore be load-tested at 250 amps for 15 seconds.

A load test can only be performed if the battery is at or near a full charge. Some electronic load testers apply a 100 amp load for 10 seconds, and then display battery voltage. This number is then compared to a chart on the tester, which compares common load testing results to CCA ratings to determine battery condition.

Life Expectancy of a Lead-acid Battery

Battery manufacturers define the end-of-life of a battery (when the battery is functionally dead) as the point at which it can no longer hold a proper charge. This can occur if a cell has shorted out, or when the available battery capacity is 70 percent or less than the battery rating.

The life of lead-acid batteries is usually limited by several factors.

Cycle life is the cumulative number of charge and discharge cycles a battery can take before its lead-plate grids or plates are expected to collapse and short out. The greater the average depth of discharge, the shorter the cycle life.

Age affects batteries because the electrochemical reactions inside them erode the lead plates. The healthier the living conditions of the batteries, the longer they will serve you. Lead-acid batteries perform better for longer times if kept at a full charge in a cool place. Buy only batteries that were manufactured recently. To be sure that you are purchasing a new battery, learn to decipher the date code stamped on every battery or ask the manufacturer. The longer the battery sits in a store, the less time it will serve you. Since lead-acid batteries will not freeze if they are fully charged, you can store them in the cold during winter to maximize their life.

Construction plays a big role in battery life too. Some designs preserve batteries better than others, and the suitability of a design for a given application plays a role also. For example, flooded lead-acid cells will typically fare worse than their VRLA cousins in operations that involve a lot of jerky motion because the immobilized plates in VRLA cells will be stressed less than suspended plates in cheap flooded cells.

Credit: becosky...

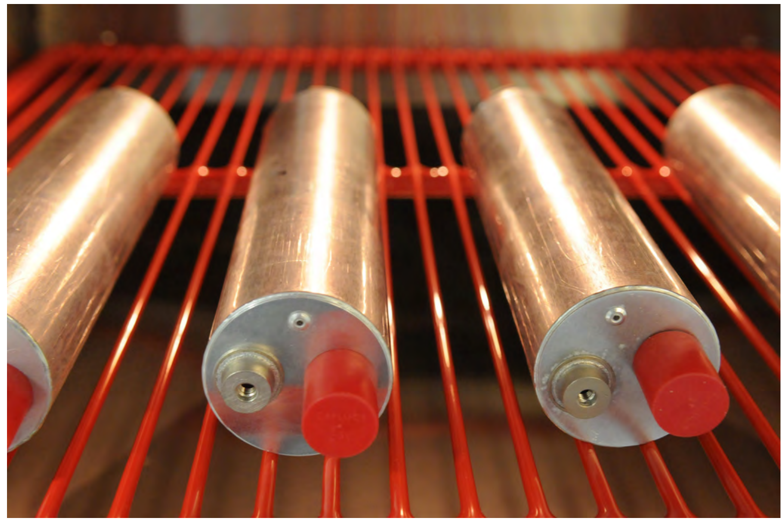
Plate thickness The thicker the plates, the more abuse and charge/discharge cycles they can take. Thicker plates are better able to survive equalization treatments that reverse sulfation. You can use weight as one guide for buying lead-acid batteries. Generally, the heavier the battery within a given group size, the thicker the plates are and the more durable the battery will be.

Sulfation is a constant threat to batteries that are not fully charged. A layer of lead sulfate can form in lead-acid cells and inhibit the electrochemical reaction that allows you to charge/discharge batteries. Many batteries could be saved from the recycling heap if they were cared for properly and equalized if necessary. As noted earlier in this module, equalization is a process that removes hard sulfation from lead plates, but the best practice is preventing sulfation by proper battery care and recharging after a discharge cycle.

LITHIUM BATTERIES

A Brief History of Lithium Batteries

Experimental lithium batteries were developed as early as 1912, but it took nearly 70 years before a commercial lithium battery was developed for a wide market. Today, lithium batteries are most associated with enhancing “portable” capabilities. For example, they are the standard battery technology for high performance in portable electronics ranging from cell phones to laptop computers. There is a diverse family of lithium chemistries available. At first glance, they might all seem to be the same, but there are exploitable, distinct differences between them. The unique nature of the various chemistries allows each type to fill special application niches.



Credit: Wes Agresta

Even with wide market adoption in the early 1990s, as societal demands for lightweight portable electronics was burgeoning, the high cost barrier and complexities in battery management circuits would prevent lithium batteries from being used widely in support of larger devices or in scaled energy-storage systems (such as large vehicles or Uninterruptible Power Supplies (UPS).

Today, lithium battery technology continues to evolve at a rapid pace. Manufacturers, driven by demands from new applications, are constantly pushing the envelope by making changes in the chemistry and structure in search of improved battery life and greater energy density.

Application Barriers

The spectrum of applications for lithium batteries is narrower than it is for some of the other battery chemistries on the market (such as lead-acid or nickel-metal hydride), further impeding their acceptance into wider markets. This is due primarily to two factors:

- Lithium batteries often require complex management to operate safely and efficiently.
- There are safety concerns related to the battery chemistry.

Battery Management

Battery Management Systems (BMS) ensure that individual battery cells are charged and maintained optimally. In a working configuration, lithium batteries usually require unique charging times, voltages, and amperage, and they can be easily and permanently damaged if they are not used with a proper BMS. Cell damage can range from significantly shortened life to general poor performance, and in extreme cases a damaged cell can overheat causing an explosion or fire. While it will not spew caustic electrolyte like a lead-acid battery, it will likely be a memorable event.

The role of the BMS is simple: *It controls the actual voltage of each cell, so that it doesn't get too high or too low.*

For these reasons, lithium batteries are used for high-performance applications where it is critical to keep weight down and maximize energy density while lead-acid batteries provide low-risk solutions needed by many users.

Credit: Wes Agresta

Safety

Safety is greatly enhanced when the use of a battery is limited to a single role, such as supporting a specific electronic device like a hand-held radio. Additionally, the power management required for "maximum protection" and "optimal operation" can be custom tailored if the battery is being limited to performing a single function.

Credit: Wes Agresta

Energy Density

Energy density is a measure of battery capacity (watt hours) divided by how much it weighs in kilograms (Wh/kg). Generally speaking, the higher the energy density a battery has the better.

The energy density of a lithium battery is significantly higher than other battery chemistries. For example, a lithium battery that weighs 35kg will provide the same amount of energy as a lead-acid battery that weighs 70kg. This is a highly desirable feature when considering the "Portable Power" market. If you were around in the early days of cell phones, you might remember the large bulky batteries that were required to operate them. If you are old enough to remember the 1970's, then you may remember that a portable communications radio often required a battery that weighed more than the radio itself.

The size and weight of a lithium battery are directly related to its "capacity". Simply put, the bigger and heavier the battery, the more energy it can store. There is one exception to this rule: Since most lithium batteries also contain an internally mounted BMS, size and weight cannot always be directly compared across "all" batteries, especially from different manufacturers. The size and weight of the BMS circuit itself will be in direct relation to the maximum power flow in/out of the battery.

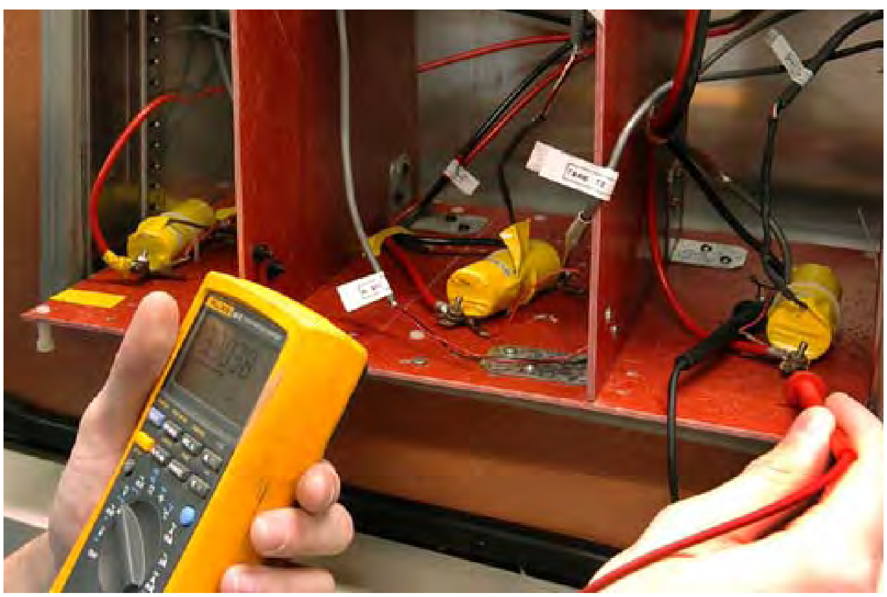
Cycle life

Lithium batteries can endure more charge/discharge cycles than other chemistries. Cycle life will range in value based on the chemistry of the cells and the conditions the battery is subjected to.

Regulatory Oversight of Lithium Cells and Batteries

In general, lithium batteries are known for their higher performance, but also for their volatility and reactivity, which makes them subject to greater control and inspection. Among the lithium battery chemistries, LiFePO4 is unique in that it is significantly safer. There are several regulatory organizations that have jurisdiction over the construction, use, and safety protocols for lithium batteries. The United Nations (UN) sets many of the basic standards used for testing, construction, and transport, but many individual nations will also set their own standards, which may differ from the UN's policies.

For example, the United States Department of Transportation (DOT) recognizes the UN guidelines as a foundation for its policies and procedures, but also puts forth its own standard operating procedures for organizations subject to its jurisdiction that must handle lithium batteries. The International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA) provide additional regulatory guidelines for international and domestic air transport. The International Maritime Organization (IMO) regulates all transport by sea-going vessels. Regulations governing the transportation of lithium batteries are strictly enforced and are revised frequently. Please consult all relevant agencies and documentation prior to shipping.



Credit: Wes Agresta

Official Definitions*

The Lithium "“Cell"

The official UN definition for a “cell” is as follows:
“Cell means a single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across its two terminals.”

Battery cells are the most basic individual components of a battery. A cell is simply one container in which the active materials can interact. The exact chemistry is often patented and proprietary to each battery maker.

The Lithium "“Battery"

The official UN definition for a “battery” is as follows:
“Battery means two or more cells which are electrically connected together and fitted with devices necessary for use, for example, case, terminals, marking and protective devices. A single cell battery is considered a ‘cell’ and shall be tested according to the testing requirements for cells.”

*From the United Nations “Transportation of Dangerous Goods”, rev. 5 - section 38

Lithium batteries are aggregate cells that have been assembled into a working configuration. There are two common types of cells in wide use:

1. Prismatic - Also known as “Large Format”
2. Cylindrical - Also known as “Small Format”

Lithium Battery Design Specificity

Lithium batteries are rarely simple “drop-in” replacements if they are being used to upgrade or replace existing batteries; rather, they are often as unique in their physical construction as the device they are powering. If an application uses a specific battery size, with a prescribed voltage and capacity, then a lithium battery often is designed specifically for the application, complete with management devices to regulate the power in and out of the battery. For example, lithium batteries used in phones often are not cross compatible with other lithium battery–driven devices.

Additionally, manufacturers will often “control” their product by ensuring specific usage through unique electrical contacts and battery shape. This also limits their legal liability against improper use of the battery.

Building System-specific Lithium Batteries

To build a battery, individual cells are placed together in a single case and connected in series. Each cell produces a certain voltage, also known as electromotive force. Any number of cells can be connected in order to provide the cumulative voltage that is required to perform specific functions. The voltage rating of a battery is directly related to the number of cells that have been wired in series. The voltage of each cell varies somewhat between brands, as each manufacturer uses slightly different chemistry. In any case, if good performance and long life are desired, an entire system must be made, or adjusted, for a specific battery type.

Lithium Battery Integration

As our mobile society has demanded more unique and complex batteries, a new market has evolved to meet the requirements for flexible integration. It is now possible for large companies as well as the individual hobbyist to create their own battery in direct accordance with their needs.

Many manufacturers are now meeting these new consumer demands by offering the basic technologies used in the construction of a battery, including a wide variety of individual lithium cells, cell balancing, and BMS technologies. The final form factor is often determined by the application and the integrator. The flexible environment of the market allows the best technologies to be integrated into a working battery for a specific application.

Lithium cells can be significantly more expensive than other chemistries such as NiMH and lead-acid, but if used properly will provide the greatest return on investment (ROI). If a battery is designed for a specific application and then sold *en mass*, it is incumbent upon the manufacturer to meet the regulatory requirements, including testing and certification, whereas a hobbyist who wishes to create a single battery for personal use can do so without the need to have the battery tested and certified.

Battery capacity

Battery capacity is generally defined as the amount of energy a battery can store, in amp-hours. In other words, the capacity is a set number of amps, discharged for a specific amount of time, until the battery voltage drops too low to be usable. This can also be a deceptive figure, because batteries can provide more amps for longer times when they are lightly drained, than they can provide for a brief high-power drain. Lead-acid batteries are usually rated for the number of amp-hours that they can provide when they are drained over a 20-hour period, reflecting typical recommended use.

Lithium batteries respond quite differently than lead-acid batteries. Lithium batteries provide power at almost full capacity regardless of the discharge rate. When they are discharged at a high rate, no change in power output is seen until the last 10 or 20 percent. At this point, power is still available, but at reduced voltage and rate. Overall capacity, in amp-hours, can be deceptive since a lithium battery can be deeply discharged, effectively using nearly all of the rated capacity. By contrast, lead-acid batteries are held to 50-70 percent of the capacity during discharge in order to extend battery life. For this reason, many people consider a lithium battery of "the same" capacity to actually have roughly twice the usable capacity of a lead-acid battery.

Operational Variance and Degradation

A reversible chemical reaction is the source of power in a battery. As with most chemical reactions, there is always variation in the efficiency and degree of completion of the reaction. Environmental factors as well as age/use-dependent changes in the concentration of the reactants and products can affect the power output of the battery. Below is a list of internal and external variables that impact the chemical reaction in the battery and, by extension, its power output.

- Temperature
- Rate of Discharge
- Charging Efficiency
- Battery Health
- Battery Age

If a battery is rated at a capacity of 105Ah, by definition it should provide 100 amps over a period of 1 hour but it is unreasonable to expect the same results every time. The capacity of a lithium battery may actually increase during the first 50 charge cycles, and not decrease until well after 1000 charge cycles. Nevertheless, improper charging or storage can quickly damage a lithium battery permanently. Furthermore, most lithium batteries perform poorly in both extreme cold or hot temperatures. There is a wide variety of electronic "battery monitors" on the market. Some of them can provide a fairly accurate estimate of power output, if they are used correctly. Most users will find that a rough estimate and conservative use are a more cost-effective solution.

LiFePO4 Chemistry = Safer Battery

A LiFeP04 battery can be installed safely in any orientation. Safety vent valves are usually not required because the BMS will not allow the battery to overheat and vent gasses. Improper charging and storing may cause the formation of crystalline “needles” that can puncture the internal separator, resulting in failure or fire, especially in lithium-ion polymer batteries. However, this is not the case with LiFePO4 batteries because the reactants that store the charge are not flammable. By contrast, all other lithium battery chemistries are volatile, reactive, and flammable. If they do overheat and catch fire, conventional halon fire extinguishers are unable to put out the fire. Furthermore, when a LiFePO4 battery is completely discharged, all of its components are inert (absolutely non reactive).

For many applications, the high degree of safety of LiFePO4 chemistry makes it the best choice despite its somewhat lower charge density.

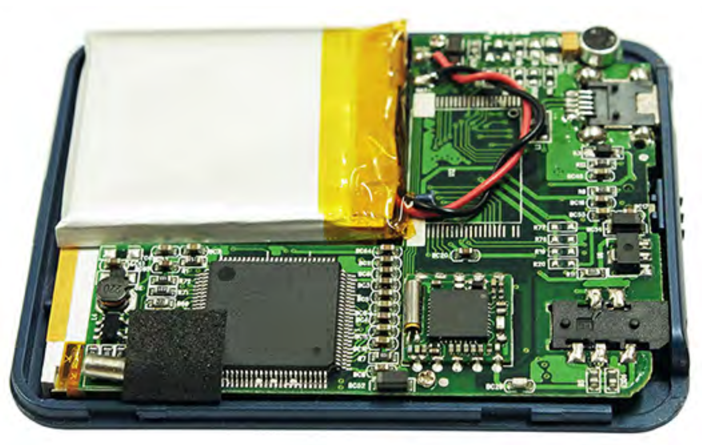
How the Chemical Reaction in a LiFePO4 Battery Works

When a charge is applied to a battery, electrons flow between the internal components. The amount of push or force of the electrons moving is known as the battery voltage.

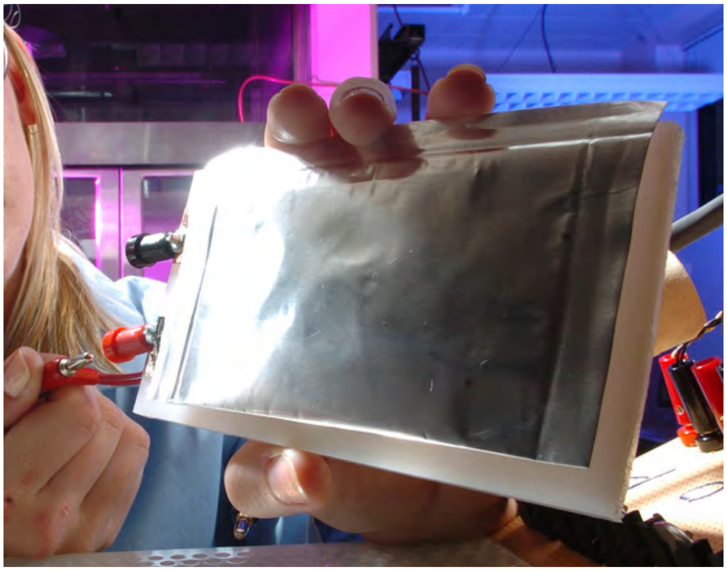
The basis of this reaction is the lithium metal binding and unbinding with the other chemicals in the electrodes at the ionic level. As power is drawn out of the battery, the metal moves from one electrode to the other, and when the battery is charged, it moves back to the original state. The metallic lithium ions literally move through the plastic separator material.

LiFePO4 Battery Voltage

The voltage of a LiFePO4 battery indicates the amount of electromotive force (or the amount of push) that moves electrons from negative to positive fields. In the LiFePO4 cell, the effective working voltage changes very little. A change as small as 1 volt, may reflect the difference between a totally dead, permanently damaged battery and one that is fully charged.



Using a simple, conventional, uncalibrated voltmeter to monitor the voltage and condition of a lithium battery is not recommended because it usually is not accurate enough to reflect the true condition of the battery.



Credit: Wes Agresta

Determining Battery Health

As a lithium battery ages, capacity decreases gradually. There is still some debate about exactly what causes a lithium battery to degrade. Possibilities include the amount of discharge (i.e., using one-third of capacity between each recharge, versus using all of it) and the rate of recharging (fast versus slow). The best solution to maintain the overall health of a lithium battery is using a proper BMS. “Abuse” can kill any battery. The best way to determine the capacity remaining in a lithium battery, is to deep cycle it with a load while monitoring its performance over time. Because the lithium battery has a relatively high cycle number capacity, doing this once or twice a year should not be detrimental to the life of the battery.

A Quick Overview of Common Lithium Battery Chemistries

<table>
<tr><th>Chemical Name</th><th>Material</th><th>Abbreviation</th><th>Short Form</th><th>Notes</th></tr>
<tr><td>Lithium Cobalt Oxide1
Also Lithium Cobalate or Lithium-ion-Cobalt</td><td>$LiCoO_2$
(60% Co)</td><td>LCO</td><td>Li-Cobolt</td><td>High capacity; for cell phone laptop, camera</td></tr>
<tr><td>Lithium Manganese Oxide1
Also Lithium Manganate or Lithium-ion-Manganese</td><td>$LiMn_2O_4$</td><td>LMO</td><td>Li-Manganese, or Spinel</td><td rowspan="3">Most safe; lower capacity than Li-cobalt but high specific power and long life.

Power tools, e-bikes, EV, medical, hobbyist</td></tr>
<tr><td>Lithium Iron Phosphate1</td><td>$LiFePO_4$</td><td>LFP</td><td>Li-Phosphate</td></tr>
<tr><td>Lithium Nickel Manganese Cobalt Oxide1
Also Lithium-Manganese-Cobalt-Oxide</td><td>$LiNiMnCoO_2$
(10–20% Co)</td><td>NMC</td><td>NMC</td></tr>
<tr><td>Lithium Nickel Cobalt Aluminum Oxide</td><td>$LiNiCoAlO_2$
(9% Co)</td><td>NCA</td><td>NCA</td><td rowspan="2">Gaining importance in electric power train and grid storage</td></tr>
<tr><td>Lithium Titanate2</td><td>$Li_4Ti_5O_{12}$</td><td>LTO</td><td>Li-Titanate</td></tr>
</table>

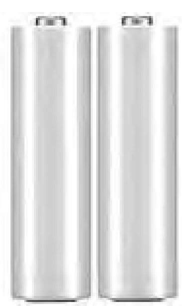
Source: batteryuniversity.com

LiFePO4 Introduction

In this section, we will focus on the Lithium Iron Phosphate (LiFePO4) battery chemistry. LiFePO4 is slightly less powerful than other commercially available Li chemistries, but it has the great advantage of using a non-flammable electrolyte, making it safe for ordinary users. LiFePO4 has about the equivalent safety characteristics as lead-acid batteries.

Physical and Operational Properties

Unlike a sealed lead-acid battery, the metal in a lithium battery is not physically configured into stacks of rigid metal plates, so there is no gross physical change of "the plates" in the battery such as occurs in lead-acid batteries (sulfation). Inside the matrix of each cell, the lithium is moving as lithium ions (Li^+). Moreover, all lithium batteries are "sealed". There is no topping up the electrolyte and no routine maintenance required. Common LiFePO4 cell types include cylindrical and prismatic (LiFePO4 chemistry is not packaged in pouch cells, another lithium cell type). It is easy to see how these were named, as they are actual descriptions of their physical attributes; they look like what they sound like:



LiFePO4 cylindrical cells are all made of the same basic components. Each cell, and the entire battery, is enclosed by a resilient plastic container. Inside the container there is a "rolled" foil, and between the foil there is a layer of permeable "separator" material. A safe, non-flammable electrolyte (unique to LiFeP04) is added to each cell and saturates the "foil" and "separator". The battery terminals are typically threaded (rather than posts) so that heavier-duty connections can be made to the load.

LiFePO4 prismatic cells make optimal use of space by using the layered approach. Small, flat versions are used in mobile devices where space is at a premium. The terminals can be oriented in any direction, which is an important feature for hand held devices. The smaller formats often have a softer, more flexible exterior and are sometimes referred to as pseudo-prismatic jellies. Larger versions of the prismatic format are used to power vehicles and are often housed in welded aluminum housings. Stronger exterior housings are often required to compensate for the structurally softer inner construction of the prismatic format. Less efficient thermal management is inherent in their design, and overheating can reduce the life cycle and cause the cells to swell. If this occurs, remove and replace the battery before there is any damage to the component using the battery.

LiFePO4 Performance Characteristics

Extremely low charge in a lithium battery can cause damage. Within the normal working range, a low charge will mean that the battery can supply “full power” but only for a short time.

If **low capacity** is the case, a lithium battery will likely have good conductivity and strong torque (power) but only for short bursts. The voltage will appear to be okay when checked with a meter, but a meter is not a “real load” on the battery, thereby giving the false impression that the battery is fine. Using the same volt-meter while the battery is connected to a real load is known as “load testing” and is a more accurate way to measure capacity, but since the working voltage range of a lithium battery is so much smaller than that of lead-acid batteries, it is still more difficult to determine capacity this way. Knowing the capacity of an aging deep-cycle battery is very important because it’s the best indication when a battery should be replaced. As mentioned previously, the best way to check the capacity of a lithium battery is to actually deep cycle it from time to time (i.e., once or twice a year) and to recalibrate any battery capacity monitor at that time. Deep cycling does not significantly affect the life of the battery due to the high number of charge cycles that lithium batteries provide.

Mismatched batteries do not age at an equal pace. If multiple batteries are combined as a bank, the battery with the lowest capacity will determine the runtime or the vitality of the entire battery bank. Uneven battery performance may also cause a BMS to shut down one or more batteries in a bank, effectively disabling the entire bank. For this reason, we recommend that all of the batteries be purchased, used, and replaced as a group at the same time.

Battery abuse is a colloquial term that simply means not caring for the battery. This is when the battery is not being used within the parameters prescribed by the manufacturer of the battery and/or the engineers who designed the system in which the battery is being used. Failure to follow the proper guidelines can significantly decrease the performance and lifetime of the battery. Storing lithium batteries in a discharged state and/or in an extreme high heat environment are two types of abuse that can cause permanent damage to lithium batteries. Either one of these forms of abuse alone could cause damage while the battery is not in service. A combination of these will (most likely) cause damage while the battery is not in service. The duration of exposure will have direct correlation to the amount of damage done. Remember that these phenomena are not unique to LiFeP04 batteries.

Equalization should never be done with lithium batteries.

Note: Our lithium-based battery systems are never factory configured for equalization. If you are mixing and matching batteries and chargers, make sure that your charger does not do periodic equalization charging, as this will ruin a lithium battery.

Gassing occurs when you attempt to charge a battery faster than it can absorb the energy. Excess charging produces heat and “boils” the electrolyte. This is not usually a problem with lithium batteries, but if they are overheated, the case may deform and bulge, which can damage or destroy the battery. If any battery of any type starts to bulge or warp, it should be taken out of use immediately to prevent the possibility of bursting or explosion.

Thermal Runaway is a very dangerous condition that can occur if batteries are charged too fast. If you have purchased an automotive jump-starting kit in recent years, you may have noticed that many of them include safety goggles. This is because some ten thousand battery explosions are reported each year due to improper jump starting and the resulting explosions. Lithium batteries can absorb current at a much higher rate, and LiFePO4 batteries do not produce the same explosive gas mixture as conventional batteries. However, some types of lithium batteries can still catch fire from thermal runaway.

Self-discharge is a measure of how much batteries spontaneously discharge on their own. The self-discharge rate of lithium batteries is so low that they can be left on the shelf for a year and still retain effectively all of their charge. For routine storage, we conservatively recommend that you check and charge the battery every three to six months if possible, as the BMS will likely be consuming small amounts of power even while everything is "off" and the battery is in storage. It is important to bear in mind that the self-discharge rate increases when lithium batteries are stored in a hot environment.

Storage (or "float") charging is not good for Lithium batteries. Lithium batteries should not be kept on a trickle charger while in storage. It is actually better for them to be slightly discharged than to be stored fully charged.

Temperature: Lithium batteries are reasonably forgiving of temperature extremes, but they do have limits. Generally, they should be kept above freezing, and below 74°C (165°F). If they are stored in a sealed or confined space, they should be kept within recommended temperature limits.

The optimum operating temperature for lithium batteries is about 25°C (77°F). If you're comfortable, the batteries will be too. Most people are aware that batteries suffer in the cold. For example, a car is most likely to have a dead battery on a cold winter day. However, many people are unaware that batteries suffer in extreme heat as well. The power and life of any type of battery can be cut in half simply by an extreme summer heatwave. Proper ventilation of closed spaces, and even simple shade from intense sun, will ensure that you can get the maximum power from your battery. Continual overheating will shorten the life of your batteries.

Note: Trying to drain (discharge, or charge lithium batteries below freezing temperatures can damage them permanently.

"Bricking" A LiFePO4 Battery As soon as the BMS senses that the cell voltage is too low to discharge, time is of the essence to place the batteries on charge. Failure to do this may cause a fatal error known as "bricking". Once the batteries reach their internal "disconnect" voltage, the voltage can fall very rapidly in the internal cells, causing the battery to "brick". This means that the battery cells are non-recoverable, and the battery module must be replaced. Here's some good news (if there is any here)... When a LiFePO4 battery is 100% discharged, the cells lose any hazardous properties. In fact, they are so inert and safe, they can be disposed-of properly and safely using any common method, even in house-hold garbage (yes, alongside the milk carton and eggshells). The ingredients used in the creation of the LiFePO4 cells are fully biodegradable.

CHARGING LITHIUM BATTERIES

Voltage, Current, and Time - The Parameters for Recharging

Charging Voltage: A lithium battery can easily be destroyed by a conventional charging system due to their different voltage range and charging response. A BMS (Battery Management System), with overvoltage and undervoltage protection should be used to ensure optimum battery life, performance, and safety. (See Appendix III for more information about .)

Charging Current: All batteries have a maximum current at which they can be charged safely. Lithium batteries have the highest acceptance rate, and fastest recharging time of all options. However, charging at the maximum allowable current can also shorten battery life. Cases of extreme over-current could result in a hazardous condition due to battery overheating and thermal runaway.

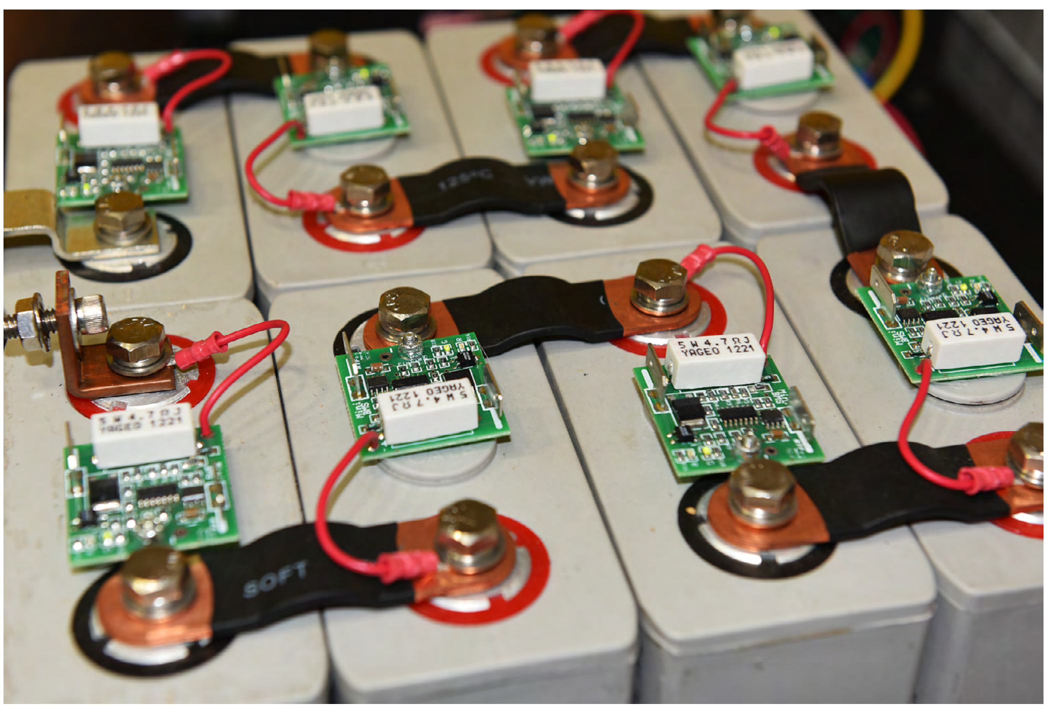
Charging Time: While the speed of charging can affect the ultimate lifetime of a lithium battery, their high acceptance rate means that they can typically be fully charged in as little as two to four hours, although conventional charging sources may typically be programmed for longer charging times. Preventing overheating and thermal issues will probably be the limiting factor for charging speed.

Charging Method For Lithium Batteries

Lithium batteries should be charged by first applying a constant charging voltage (similar to the bulk charging stage) and then, when the battery has almost reached a full charge state, maintaining that voltage but allowing the charging amperage to taper off as the charge completes.

Many commercial chargers apply three charging stages: bulk, acceptance, and float. These three stages are not the appropriate charging profile for lithium batteries.
Since no lead-acid battery charger is designed to provide this type of charging profile, we suggest that you only charge a lithium battery with the charging equipment or system that it came with.

In a pinch, you can use a regulated ("Lab") power supply or a simple fixed-voltage regulated charger to bring the lithium battery back up to its rated voltage, and then simply stop charging it. This will recharge the battery fairly effectively, as long as you monitor battery temperature, and ensure that the charging current is not excessive, because these factors will create excess heat. This method is actually better than misusing a lead-acid "smart" charger. However, it is still not as good as using the charging system that came with the battery, and should not be used as a regular means of charging. If you cannot accurately measure and set the proper voltage, do not try to recharge the battery. The BMS will try to protect the battery from overcharging, but it has limited abilities to do so. It is not a charge controller; it is a safety device.



Battery Charging Devices

The integral BMS in Solar Stik's lithium batteries will protect against some types of damage, as it is controlling what power goes into the lithium battery.

Simple battery chargers: Most garage and consumer (automotive) battery chargers are bulk charge only, and have little, if any, voltage regulation. While they are fine for a quick boost to low lead-acid batteries, their lack of proper voltage regulation could easily damage a lithium battery if used for extended amounts of time.

Regulated chargers: A voltage-regulated charge controller, such as a Lab Power Supply, is designed to supply constantly regulated voltage to batteries. If these are set to the correct voltages for the batteries, the BMS in Solar Stik's Lithium batteries will keep them charged without damage. Chargers such as these are sometimes called "taper chargers". Remember that lithium batteries, unlike lead-acid, do not need, nor do they benefit from long-term, trickle charging. They are best charged, and then used or put away.

Battery charge controllers: These are regulators that go between a charging source, such as solar panels, and the storage batteries. Regulators for solar systems are designed to keep the batteries charged to peak voltage without overcharging. This is typically the way that Solar Stik systems are configured, with all parts of the system optimized for battery types and capacity.

Temperature-compensated charging

With any type of battery, the actual charging voltage should be adjusted for the ambient temperature of the battery. As batteries charge they generate internal heat, and when they charge quickly they can generate enough heat to cause damage, or to shorten the life of the battery. The integral BMS monitors internal battery temperatures, but all it can do is completely cut off the charge to prevent excess temperatures from causing damage.

Cell Balancing

One of the jobs of the BMS is to monitor the condition of each individual cell that makes up a battery. For a variety of reasons, each cell will perform somewhat differently. To minimize these differences, BMS components called Protection Circuit Modules or Protection Circuit Boards (PCMs or PCBs) are connected to each cell. The PCBs constantly monitor and report critical parameters of each cell and make small adjustments to correct for any differences between cells. Balancing or equalizing all parameters of each cell in a battery is critical to ensure full life and capacity from a lithium battery.

Battery Capacity Testing

Lithium batteries can be tested in several ways. A voltage test, with a calibrated voltmeter, can be useful, but the best way to test a lithium battery is to perform an actual "load test". Load testing removes the energy from a battery, and measures how many amps are removed and then replaced after the battery is recharged. This measures the "capacity" of the battery, and it is the most accurate test to determine the health of a battery.

A load test can only be performed if the battery is at or near a full charge. Load testing can be done with a load test instrument, which usually uses a large resistor to drain the battery, or with conventional loads, like headlights, heaters, coolers, or whatever equipment normally puts a heavy load on your battery when the charging supply is turned off. If you have a battery monitor or amp meter, this can be used to see how many amps have been drawn from the battery over a period of time. If you do not have a meter, you can make a rough determination by calculating the cumulative energy consumption of the loads (lights, heaters, etc.), and multiplying that number by how long it takes before you see performance degrade.

Some electronic load testers apply a 100 amp load for 10 seconds, and then display battery voltage. However, this procedure is meaningless for lithium batteries because of their different ability to power heavy loads. Because lithium batteries are so robust, testing them once or twice a year will not make any real difference in their life or capacity, and places an insignificant drain on them.

Conversion Efficiency

Conversion efficiency denotes how efficiently a battery converts an electrical charge into chemical energy and back again. The higher this percentage, the less energy is converted into heat (heat is lost energy). Conversion efficiency also means that the battery can be discharged faster without overheating. (This assumes all other factors are equal.) The conversion efficiency of lithium batteries is virtually 100%.

The lower the internal resistance of a battery, the better its conversion efficiency will be. Lithium batteries have a very low internal resistance, and that is one reason they are both more efficient and more powerful than other batteries, pound for pound.

No other batteries are as close to 100% efficient at converting charging amp-hours back into stored amp-hours. The efficiency of lithium batteries and their low internal resistance are some of the reasons why they may recharge 3 to 4 times more quickly than lead-acid batteries. However, this also means they put a higher demand on conventional alternator or generator charging systems, so the entire system should be engineered with these differences in mind. Typically, alternators and fossil fuel–powered generators are not designed to run at full output for sustained periods. Solar panels, on the other hand, have the unique advantage that there is no problem of "waste heat" being generated as the panels charge the battery, so this is not a concern.

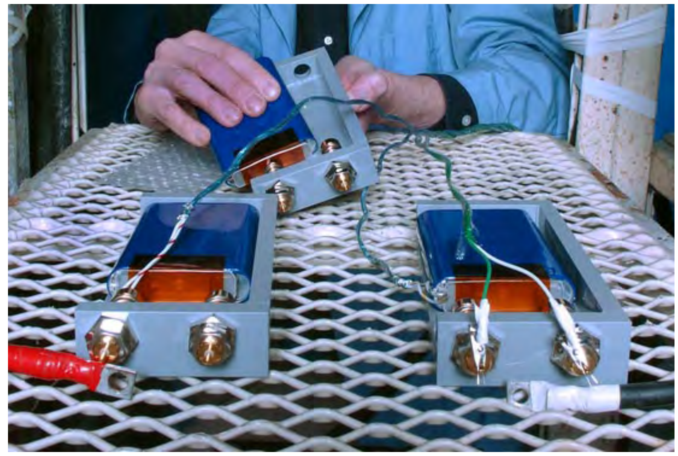
Life Expectancy of a LiFePO4 Battery

A battery is functionally dead when it can no longer hold a proper charge, or when the available battery capacity is unacceptably less than the original battery rating.

The life of lithium batteries is usually limited by several factors:

Cycle life is the cumulative number of charge and discharge cycles a battery can provide. With all battery types, the greater the average depth of discharge, the shorter the cycle life. However, LiFePO4 batteries typically will provide 2000–5000 cycles (to complete discharge), approximately 500% more than the best lead-acid batteries. Exactly how many cycles a battery can be expected to provide can be referenced from the technical data comparing depth of discharge and cycle life. Proper recharging, controlled by the BMS, is critical in obtaining the best performance.

Age does not appear to have a significant impact on lithium batteries, as long as they are properly charged when stored. Remember that float charging will shorten the life of a LiFePO4 battery, so if they must be stored for long periods, it is better for them to be stored with a 40 to 50 percent charge, rather than a full charge. The BMS in Solar Stik lithium batteries will consume a tiny bit of power, so the battery should be checked or charged every 3–6 months while in storage. Unlike a lead-acid battery, which forms sulphates if not charged monthly, a lithium battery can be stored and ignored for months at a time.



Credit: Wes Agresta

Construction plays a big role in the life of a battery. If the separator film in a lithium battery is too thin, it may puncture over time, resulting in failure of the battery. If the case material is too thin and weak, it may warp from overheating. As with anything else, the overall quality and assembly method makes a difference.

Summarily, the overall life expectancy of LiFePO4 batteries is much higher than many other battery types, provided they are properly built, and used with a good BMS to ensure they are properly charged and not abused. Even though lithium batteries are the most expensive type of battery to purchase, they may be the most economical battery over the long run.

LiFePO4 Storage

DO NOT STORE ANY BATTERY IN A DISCHARGED STATE! DAMAGE WILL OCCUR!

Quick Comparison of LiFePO4 and Sealed AGM Lead-acid Batteries

Initial purchase price: AGM lead-acid is much cheaper at the point of purchase than LiFePO4.

Long-term price: LiFePO4 may actually cost the same or less, based on total number of cycles and total number of watts provided.

Weight: For an equivalent capacity, AGM lead-acid is about two times heavier than LiFePO4.

Size: AGM lead-acid and LiFePO4 batteries are available in similar physical sizes.

Maintenance: Both sealed lead-acid and LiFePO4 batteries require and allow no electrolyte maintenance.

Abuse: AGM Lead-acid can sometimes recover from more abuse, if electrolyte levels can be restored. If a LiFePO4 battery is punctured, it should be removed from service immediately to protect against fire danger.

Safety: AGM lead-acid (of all types) can result in hydrogen explosions if improperly charged. LiFePO4 batteries may catch on fire, but are more tolerant of high charge and discharge rates.

Fire safety: AGM lead-acid batteries contain a water-based electrolyte and rarely combust. LiFePo4 uses a non-petroleum electrolyte, so it presents no special fire dangers and can be extinguished by conventional means.

Charging systems: Charging systems are readily available and interchangeable for lead-acid batteries. LiFePO4 batteries require a specific charging logic, and should be used with a system designed for them.

Storage: Sealed lead-acid batteries self-discharge slowly and can be damaged permanently from sulfation when allowed to discharge in storage (unless kept on a constant float charge). Lithium batteries have extremely low self-discharge rates and require only occasional (i.e. three to four times a year) storage charging.

Starting (SLI) versus deep-cycle types: While lead-acid batteries must be purpose-built as one type or another, to present the best storage or the best impulse power, this is not an issue for lithium batteries. Any lithium battery can be used for either purpose, with good performance and no long-term damage to the battery.

Battery capacity ratings: Because of the differences in performance and the abilities of the two chemistries, direct comparison of the two in terms of capacities can be deceiving! Since a lithium battery can be deep cycled so much further and so much more often than a lead battery, should you compare a 50Ah lithium battery directly to a 100Ah lead-acid battery? After all, the performance will be similar, even though the “capacity”, size, and weight will not be. When you see capacity ratings and comparisons, make sure that they are giving the specifics of how that comparison was made.

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MODULE SIX

Inverters

INVERTERS

Battery-based 12VDC electrical systems are becoming progressively more common as our society becomes increasingly mobile. They are finding applications in cars, recreational vehicles (RVs), and boats. Additionally, many new AC appliances have Energy Star ratings, to demonstrate that they operate more efficiently and use less power. This increases the potential to operate home AC appliances from a DC power source.

To convert, direct current (DC) from a battery into household alternating current (AC) power, a power inverter must be used.

Power Inverters

Power inverters of all shapes and sizes are available for purchase at establishments ranging from local automotive and drug stores to big-box retail outlets.

Most household appliances require a particular type of inverter, and associated waveform, but because of the flood of power inverters in the marketplace, the consumer can be overwhelmed when choosing an inverter. This section is intended to help you understand how to select the correct inverter for a particular appliance or application. It also explains why certain inverters cost more than others.

These principles can apply to all models of inverters whether they are purchased from Solar Stik or not.

It is important to remember that a Solar Stik System is, by itself, a portable DC system (battery storage with solar-powered recharging) and that the basic operating voltage is 12V or 24VDC.

Choosing the Appropriate Inverter

There are some distinct differences between the various types of inverters.

Typically, a user will not shop for an inverter based on its physical size, but rather its power (in watts, W), handling ability, and the type of output waveform it has. There are two types of waveforms:

- Pure sine wave
- Modified Sine Wave

If a shops for an inverter based on its physical size, to accommodate available storage or installation space, then the user might be restricted to using an inverter that has less than the required output or the less favorable waveform type.

Power inverters for 12V generators range in output from as few as 20 to as many as 10,000 watts. Moreover, many inverters have additional, incorporated features such as battery chargers and transfer switches.

Higher-wattage output inverters usually are installed in a fixed location, such as a boat, an RV, or even a residential building with a roof-mounted solar panel. Most mobile applications for inverters, however, usually require less than 5000 watts. Generally speaking, the following discussion applies to inverters in mobile or portable applications.

Three Categories of Portable Inverters

There are three categories of portable DC to AC inverters:

Low Wattage
Less than 200W Power Output

Medium Wattage
Between 200–800W Power Output

High Wattage
Greater than 800W Power Output

Choosing an inverter for any specific application should be based on two factors:

- **Power consumption** - Watts (W) or Amps (A) used by the appliance
- **Type of appliance** - Sensitive electronics versus motors, lights, etc.

Inverter Ratings

Inverters are usually rated in continuous power, but sometimes they are rated according to their peak power or surge power.

- Continuous power is the total watts the inverter can deliver continuously.
- Peak or surge power is the amount of power that the inverter can provide momentarily when equipment or an appliance first starts up.

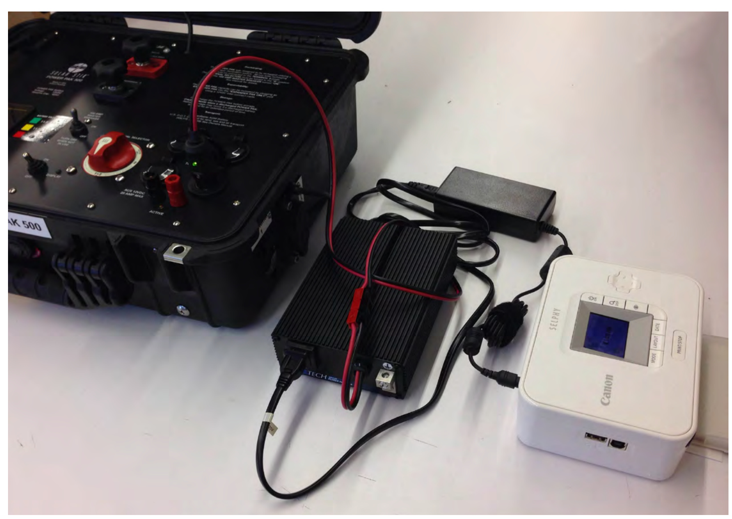
For example, induction motors (which are often found in devices such as refrigerators, freezers, or pumps) may have a momentary start-up surge of up to 800 percent of the appliance's power rating.

Some inverters have no peak surge rating stated because they have a "soft start" feature. Soft start gradually increases the output voltage, thereby avoiding the momentary peak surge that occurs when an appliance starts.

Determining an Appliance's Power Consumption

Selecting the best inverter for an application starts with finding the operating watts for the appliance. This can be found by referring to the specification plate on the appliance. You can also find this information in the appliance manual, from the appliance supplier, and often on the Internet. You need to know the continuous rating in either watts or amps, and the peak-surge rating in either watts or amps.

It is not possible to determine the correct inverter for the application without the power information of the appliance. If published information is not available, there are also low-cost, plug-in meters that will directly read AC appliance power consumption in watts.



The Solar Stik System operates at 12VDC, so we can convert either watts (P) to amps (A) or amps to watts by using the following formulas.

$$A = P \div V$$
$$\text{amps} = \text{watts} \div 12$$

$$P = V \cdot A$$
$$\text{watts} = 12 \cdot x \text{ amps}$$

Once the power requirements for the appliance or system have been determined, the appropriate inverter can be selected. **Note**: It is always advisable to build in a safety factor by overrating an appliance's continuous power rating by 20 to 23 percent.

For example, if an appliance continuously draws 240 watts, then an inverter with a rating of 300 watts continuous output should be selected (240W · 120% = 288W).

Determining an Appliance's Peak or Surge Load

When determining the peak load of an appliance, take the rated power consumption and multiply it by three:

$$\text{Peak or Surge Power} = 3 \cdot P$$

Therefore, if an appliance is rated for 300W continuous usage, then it is reasonable that the start-up load may be 900W.

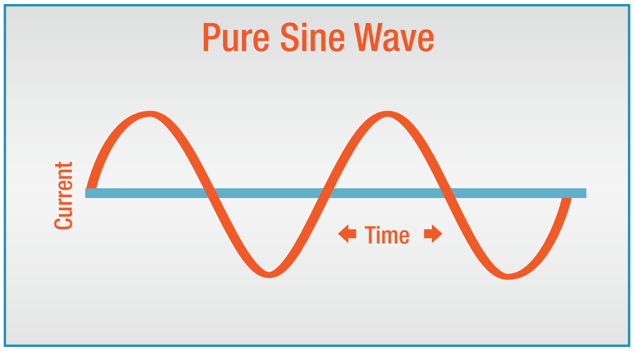
There are a few, noteworthy types of appliances that require very high peak start-up power.

- Ordinary incandescent lamps and quartz halogen lamps need as much as 10 times the start up wattage as their operating wattage
- Pumps or compressors that are under full load can require as much as eight times the start up wattage or current as their operating wattage. This is sometimes labeled as locked rotor current.

Credit: Kenny Louie

Choosing the Correct Inverter Waveform

Inverters are classified as producing either pure sine wave (PSW) output or modified sine wave (MSW) output. The PSW output waveform is shown in the following drawing.



A pure sine wave (also referred to as a sinusoidal) is produced commercially by rotating machinery (a generator). This is the type of waveform provided by electric utility companies. This type of power is available anywhere an outlet is tied to the power grid, such as in homes or businesses.

A pure sine wave inverter reproduces this waveform through the use of advanced internal circuitry.

Advantages of Pure Sine Wave Inverters

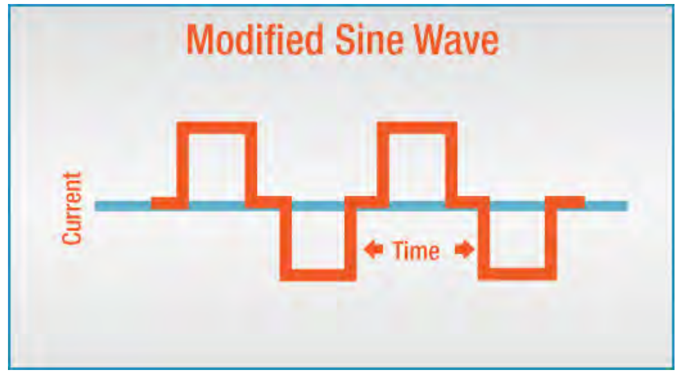
- Is most compatible with household AC power
- Is the best type of waveform for all AC electrical appliances.
- Eliminates interference, noise, and overheating.
- Reduces audible and electrical noise in fans, fluorescent lights, electronics gear, and magnetic circuit breakers
- Prevents crashes in computers, unreadable print-outs, and glitches and noise in monitoring equipment
- Can be efficiently electronically protected from overload, over- and under-voltage, and over temperature conditions.
- Allows inductive loads like microwave ovens and variable-speed motors to operate properly, quieter, and cooler
- Enables appliances that use pure sine wave power to produce full output
- Some appliances, such as variable speed drills and bread makers, will not work properly without pure sine wave power

Disadvantage of Pure Sine Wave Inverters

- More expensive than modified sine wave power inverters
- Physically larger than modified sine wave power inverters

Modified Sine Wave Power Inverters

A modified sine wave inverter (also referred to as non-sinusoidal or step-wave) is much different from a pure sine wave power inverter in the following ways



- Waveform output is step-shaped
- AC appliances are not specifically designed to work with this type of inverter waveform output, although many appliances will work properly with a modified sine wave inverter. The result is that some appliances take more power to operate with a modified sine wave inverter, thereby reducing the efficiency of the entire electrical system.
- Some appliances may not work correctly; for example, some fluorescent lighting may not get as bright, or may make buzzing noises.
- Certain appliances with digital clocks or electronic timers may not work properly with this type of inverter because the waves are rougher and cause extra noise to be created in the circuitry.
- Some appliances that use electronic controls will not be able to vary speed or temperature when using modified sine wave power
- Some appliance motors may produce more heat and burn out when they are operating

The following appliances may experience problems when operated from modified sine wave inverters:

- Electronic equipment
- Audio systems
- Wall-mounted light dimmers
- Power tools with variable speed controls that have cords
- Some battery chargers for cordless tools
- Devices with speed or microprocessor controls
- Medical equipment
- Lamp dimmers

Advantages of Modified Sine Wave Inverters

- Substantially less expensive than the pure sine wave inverters, which can be a good thing
- Readily available, and commonly used and found in the marketplace.
- It can sometimes be difficult to find anything other than modified sine wave inverters
- Smaller in physical size for the same power output as its pure sine wave counterpart

Disadvantage of Modified Sine Wave Inverters

- Lower quality construction
- Not compatible with all AC appliances

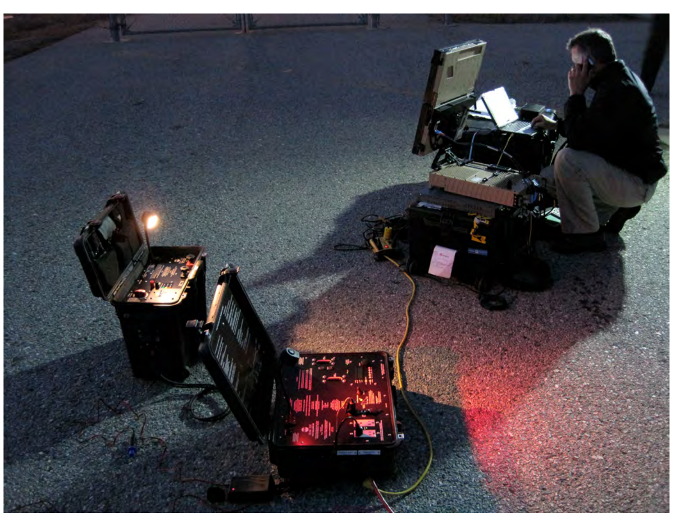
Proper Inverter Connection

Regardless of the type of inverter you select, you will need to connect it properly. Low wattage inverters (usually less than 200W) often come equipped with a 12VDC plug and can be plugged into any 12VDC socket, such as the power outlet in a car.

Medium wattage inverters (200W to 800W) are often supplied with DC cables that must be connected directly to a battery.

Higher wattage inverters (800W and over) usually require larger cables that are not typically supplied by the inverter manufacturer (though Solar Stik Inverter Paks always come pre-equipped with the proper cables). It is typically the responsibility of the installer or owner to purchase the correct size (gauge) and length of cable, according to the information supplied in the inverter manual.

If using a high wattage inverter purchased from a retailer, it will probably be necessary to purchase inverter-to-battery connection cables. There is a general rule to remember: the connection cable size depends on the distance between battery and the maximum amount of current draw the inverter will require from the battery. It is good wiring practice to use the thickest gauge wire available and in the shortest length practical. If an inadequate cable is used, it may cause the inverter to sense that the DC voltage is low and simply shut down. Incorrectly sized cables can overheat and even cause fires. If you are unsure about the proper cable size, please consult a qualified individual.



Batteries and Inverters

12V batteries are rated by the amount of energy that they can store. For example, deep-cycle batteries are designed to supply power for a long period of time and tolerate repeated discharge and charge cycles. They are rated by their total capacity in amps.

Vehicle batteries, also known as starting batteries, are often rated in cold-cranking amps. These batteries are designed to supply short-duration bursts of power, such as starting a fuel-driven car. After an engine starts, an alternator quickly replaces energy that was used during the engine start. Engine starting batteries are not suitable for deep-cycle use, because they will have reduced life if not charged immediately after engine start.

Low-Wattage Inverters

Deep-cycle batteries like the ones used in the Solar Stik Power Pak easily handle light duty inverters. Most vehicle starting batteries will support a low wattage inverter for 30 to 60 minutes. Actual operating time will vary depending on the age and condition of the battery, and the AC appliance powered by the inverter. If you use a light duty inverter that is powered through a DC accessory socket, and the vehicle engine is turned off, you should periodically run the engine for 15 minutes to recharge the battery.

Medium and High-Wattage Inverters

It is strongly recommended that only deep-cycle batteries be used for any inverter with a continuous output of 200W or more. This will ensure that you have several hundred complete charge and discharge cycles. If you use a normal vehicle starting battery to support a heavy-duty inverter, it will quickly fail after repeated charge/discharge cycles (starting batteries are not designed to perform this type of work).

When the inverter operates power-hungry appliances with continuous loads for extended periods, it will drain the battery to the point where the battery has insufficient energy to support the inverter. In these cases, it's a good idea to have extra deep-cycle batteries (extra battery capacity such as the Expander Pak) to extend the appliance operating time.

Proper Planning

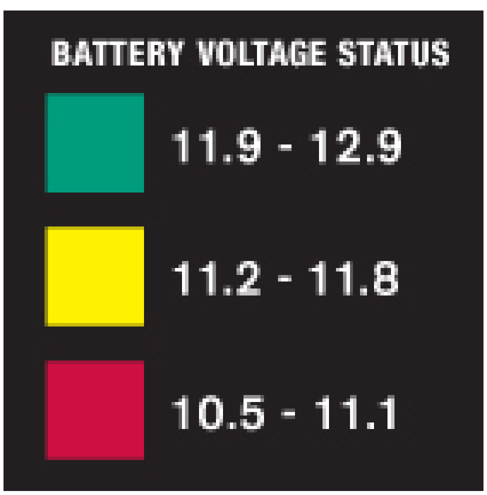
Proper planning is important when considering battery capacity. All power inverters have a low-battery alarm that sounds when the battery voltage becomes low, and all have a low-voltage shut-down function that prevents damage to the battery if the voltage drops below 10.5V. If the battery capacity is insufficient for the load size, the batteries will rapidly discharge and the user will have to deal with an unexpected shutdown.


Credit: Nomadic Lass

Keeping the batteries fully charged at all times should be the focus for the user. This will ensure that there is always enough stored energy to meet the appliance demands. There are many methods to achieve this, but the simplest is:

IF YOU ARE NOT USING THE APPLIANCE, TURN IT OFF!

The Solar Stik System was designed for continuous operation from the Power Pak. Inverters convert power, so if a connected AC appliance is turned off, the inverter draws proportionally less power from the Power Pak battery. This lowered inverter output allows for recharge time. Power from the Pak can be used by the inverter or appliance whenever it is needed; even while the Solar Stik solar generator is connected and charging.



Inverter Operation Runtime

Inverters will continue to operate as long as there is sufficient battery power available. A battery's voltage is a direct indication of its state of charge.

For example, a 12V battery that has a static (no-load, no charge) voltage of 13.2V is considered 100 percent charged. A 12V battery that has a static voltage of 10.5V is considered dead. The Voltage range in between these upper and lower Voltage values is used to determine the battery's state of charge.

Inverter and Battery Derating

Inverter output will be reduced in high temperatures. Consult the manufacturer's specific literature to determine how much reduction in power output can be expected in relation to increased ambient temperatures.

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APPENDICES

APPENDIX I: **DANGERS OF EMP**

Causes of EMP

Generally there are two causes of EMP, nuclear and solar. The effects of each can be very different.

Solar EMP

In the case of solar EMP, the damaging factor is GIC (geomagnetically induced current). In this case, the currents in the extreme upper atmosphere and magnetic field (which are caused by solar flares) can produce currents (GIC) in long conductors on the earth's surface (electrical grids and pipelines). Typically these effects are greater near the poles of the earth than near the equator, and for the most part the equipment at risk is connected to the grid.

Nuclear EMP

In the case of nuclear EMP, there are three factors involved, E1, E2, and E3 pulses.

The E1 pulse is generated when gamma radiation knocks electrons out of the atoms in the upper atmosphere, producing an electric current that is focused downward by the earth's magnetic field, and generally is directed away from the poles. This is the most damaging pulse of the nuclear EMP. It travels near the speed of light and lasts only nanoseconds.

This pulse is more likely than the others to affect equipment, but it is also simple to protect stored, non-operating equipment from it by using a Faraday cage or metal enclosure.

The E2 pulse is a result of scattered gamma rays produced by weapon neutrons. It is slower and occurs after the E1 pulse and generally is less powerful than the electromagnetic pulse caused by a lightning strike. If the equipment was not damaged by the E1, the E2 probably will not affect it.

The E3 pulse is very different than the E1 or E2. It is an even slower pulse, lasting up to several minutes. It is caused by a nuclear detonation pushing the earth's magnetic field out of place, followed by a restoration of the field to its natural position.

Like a severe solar flare, the E3 can produce geo-magnetically induced currents (GIC) in long electrical conductors, damaging the grid and other equipment connected to it.

Variation in Power

There is great variation in the power of these EMPs depending on the explosions location, your location with respect to the earth's magnetic field, day-side or night-side of the earth, and the type of explosive media used in the case of a nuclear EMP.

Protecting against EMP

The best protection from EMP in either case is to have the equipment stored, as opposed to deployed and operational.

Deployed solar panels with long cables can act as antennae to collect the damaging currents, conducting them to your equipment. If this happens, the batteries will not be harmed but most of the electronics will.

It will help to store the equipment in a metallic enclosure, such as a metal shed or a room lined with sheet metal or copper mesh. Smaller boxes can be wrapped with copper mesh, stainless window screen, or aluminum foil. It is important that they be totally enclosed (no open holes or open floor).

EMP currents differ from lightning in that they are not trying to get to earth ground; they are simply running free in a straight line.

Metal shielding enclosures should only be grounded if the ground wire can be very short. Long lengths of ground wire can collect the currents and actually increase the probability of damaging your equipment.

Solar Stik System and EMP

Storing one of our systems for use after an EMP is a great idea. Don't keep it connected to the grid. It cannot be predicted if the system will be damaged during exposure to the EMP, but the odds are very good that if the equipment survives the nuclear blast, it will work afterward.

APPENDIX II: **BATTERY MANAGEMENT SYSYTEM (BMS)**

BMS means different things to different people. To some it is simply Battery Monitoring, keeping track of the key operational parameters–such as voltages, currents, and the battery internal and ambient temperature–during charging and discharging. The monitoring circuits normally provide inputs to protection devices which would generate alarms or disconnect the battery from the load or charger if any of the parameters stray out of limits.

For the power or plant engineer responsible for standby power whose battery is the last line of defense against a power blackout or a telecommunications network outage BMS means Battery Management Systems. Such systems encompass not only the monitoring and protection of the battery, but also methods for keeping it ready to deliver full power when called upon and methods for prolonging its life. This includes everything from controlling the charging regime to planned maintenance.

For the automotive engineer, the Battery Management System is a component of a much more complex, fast-acting Energy Management System and must interface with other onboard systems such as engine management, climate controls, communications, and safety systems. There are thus many varieties of BMS.

BMS Building Blocks

There are three main objectives common to all Battery Management Systems:

- Protect the cells or the battery from damage
- Prolong the life of the battery
- Maintain the battery in a state in which it can fulfill the functional requirements of the application

To achieve these objectives the BMS may incorporate one or more of the following functions:

Cell protection: Protecting the battery from out of tolerance operating conditions is fundamental to all BMS applications. In practice the BMS must provide full cell protection to cover almost any eventuality. Operating a battery outside of its specified design limits will inevitably lead to failure of the battery. Apart from the inconvenience, the cost of replacing the battery can be prohibitive. This is particularly true for high voltage and high power automotive batteries which must operate in hostile environments and which at the same time are subject to abuse by the user.

Charge control: This is an essential feature of BMS. More batteries are damaged by inappropriate charging than by any other cause.

Demand management: While not directly related to the operation of the battery itself, demand management refers to the application in which the battery is used. Its objective is to minimize the current drain on the battery by designing power saving techniques into the application's circuitry and thus prolong the time between battery charges.

SOC determination: Many applications require a knowledge of the state of charge of the battery or of the individual cells in the battery chain. This may simply be for providing the user with an indication of the capacity left in the battery, or it could be needed in a control circuit to ensure optimum control of the charging process.

SOH determination: The state of health is a measure of a battery's capability to deliver its specified output. This is vital for assessing the readiness of emergency power equipment and is an indicator of whether maintenance actions are needed.

Cell balancing: The many cells that constitute a battery can sometimes charge and discharge at different rates, depending on the cell temperature, age, and factors that occur during manufacture of the cells. Over time, these differences will become amplified if they are not corrected. It is important that while charging and discharging, the balance between all cells is maintained. If cells are out of balance, the entire battery pack is shut off when the weakest cell drops below the lower voltage limit, even if other cells are still not completely discharged. Cell balancers are usually placed throughout the cell circuit in order to maintain a balanced charge throughout the entire battery and thereby extending the life of the battery.

History (Log Book Function): Monitoring and storing the battery's history is another possible function of the BMS. This is needed in order to estimate the SOH of the battery, but also to determine whether it has been subject to abuse. Parameters such as number of cycles, maximum and minimum voltages and temperatures, and maximum charging and discharging currents can be recorded for subsequent evaluation. This can be an important tool in assessing warranty claims.

Authentication and identification: The BMS also allows the possibility to record information about the cell, such as the manufacturer's type designation and the cell chemistry, which can facilitate automatic testing, and the batch or serial number and the date of manufacture, which enables traceability in case of cell failures.

Communications: Most BMSs incorporate some form of communications between the battery and the charger or test equipment. Some have links to other systems interfacing with the battery for monitoring its condition or its history. Communications interfaces are also needed to allow the user access to the battery for modifying the BMS control parameters or for diagnostics and testing.

Summary

So, what's all this about "permanent damage without a proper BMS"? It's simple, really. Someone has to pay very close attention to the voltage and heat levels in any type of lithium battery. Allow the voltages to get low–for any reason in any cell in the battery or for the battery as a whole–the battery is quickly, permanently ruined. If you allow the voltages to get too high or the temperatures to get too high, not only is the battery ruined, but you may have a dramatic fire.

This is not unique to lithium batteries. You can ruin a lead-acid battery, a nickel-cadmium battery, a nickel-metal hydride battery, or any other rechargeable battery the same way. But since lithium batteries are so expensive, and they store so much more energy in a small package, managing the battery very closely becomes more critical. Much like the engine control unit (ECU) in modern cars, a BMS should work invisibly and reliably, monitoring systems and information that the driver doesn't even know about.

"So, there's a computer in my battery?" There should be. And with a Solar Stik System, there certainly will be. Many off-the-shelf lithium batteries are sold without a BMS, allowing or requiring the user to build, buy, or design one according to their own specific needs. But when a lithium battery is sold as part of a complete package, from the small battery in your cell phone to the large battery on an electric car, you will find the manufacturer always includes a BMS, for reasons of both safety and performance. For you, the Solar Stik customer, civilian or military, the integrated BMS is something you don't need to worry about. There are no adjustments to be made and no configurations to be set. That's all been done for you. The BMS is constantly looking at the voltage level of each cell, as well as the battery voltage overall.

Since the BMS is always monitoring the battery, even when "everything" is turned off, that means there is always some drain on the battery. So, if you plan to store your lithium-powered equipment, it should be given a routine maintenance recharge every couple of months. The drain from a BMS can kill a battery that has been left in storage and ignored for too long!

The Solar Stik BMS also performs an advanced function called "cell balancing", which means that if any individual cell in the battery has a slightly higher or lower charge level than what is normal, the BMS will attempt to adjust the charge on that specific cell, to optimize the performance of the entire battery. If all of the cells cannot be brought within the same safe range, the BMS will shut down the battery for safety. This is unlikely to be an issue unless the battery has been badly damaged by improper storage, improper charging, or physical abuse. The BMS decides if it is safe to use the battery, or not. And if it decides the battery should not be used, it shuts the battery down. The BMS uses electronic components that are not user replaceable or resettable. Please do not attempt to tamper with a BMS that has shut down a battery!

If the BMS has disconnected your battery, assume there is something wrong with it and promptly remove it from service until a trained technician can inspect it, or return it to Solar Stik for examination. A battery that has been shut down should be stored in a safe place, or disposed of in the proper manner if it cannot be sent out for inspection. Tampering with a BMS or attempting to bypass it could result in fire or explosion.

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