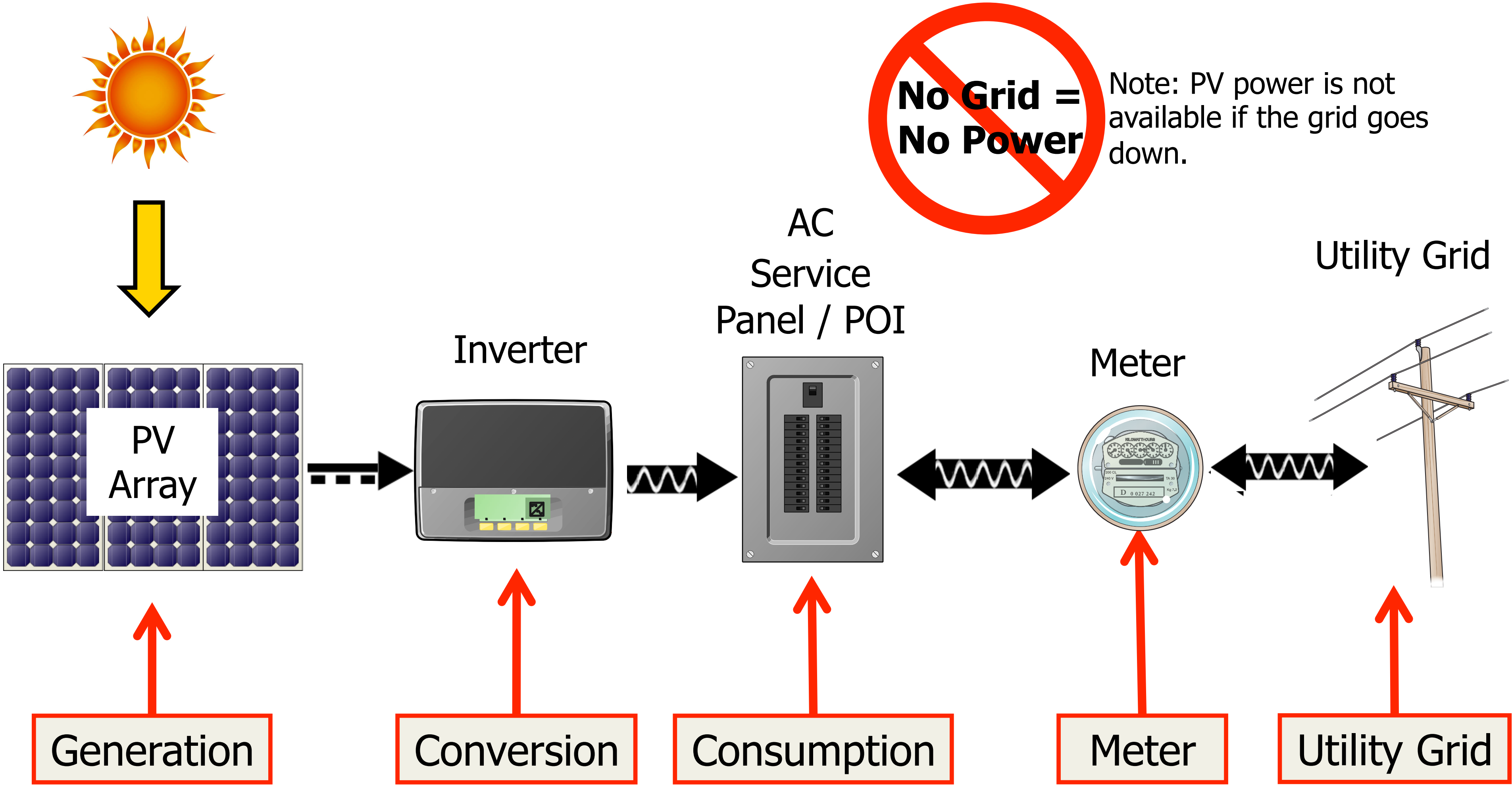
AC and DC Coupling: Multimode, Stand-Alone, and Microgrids

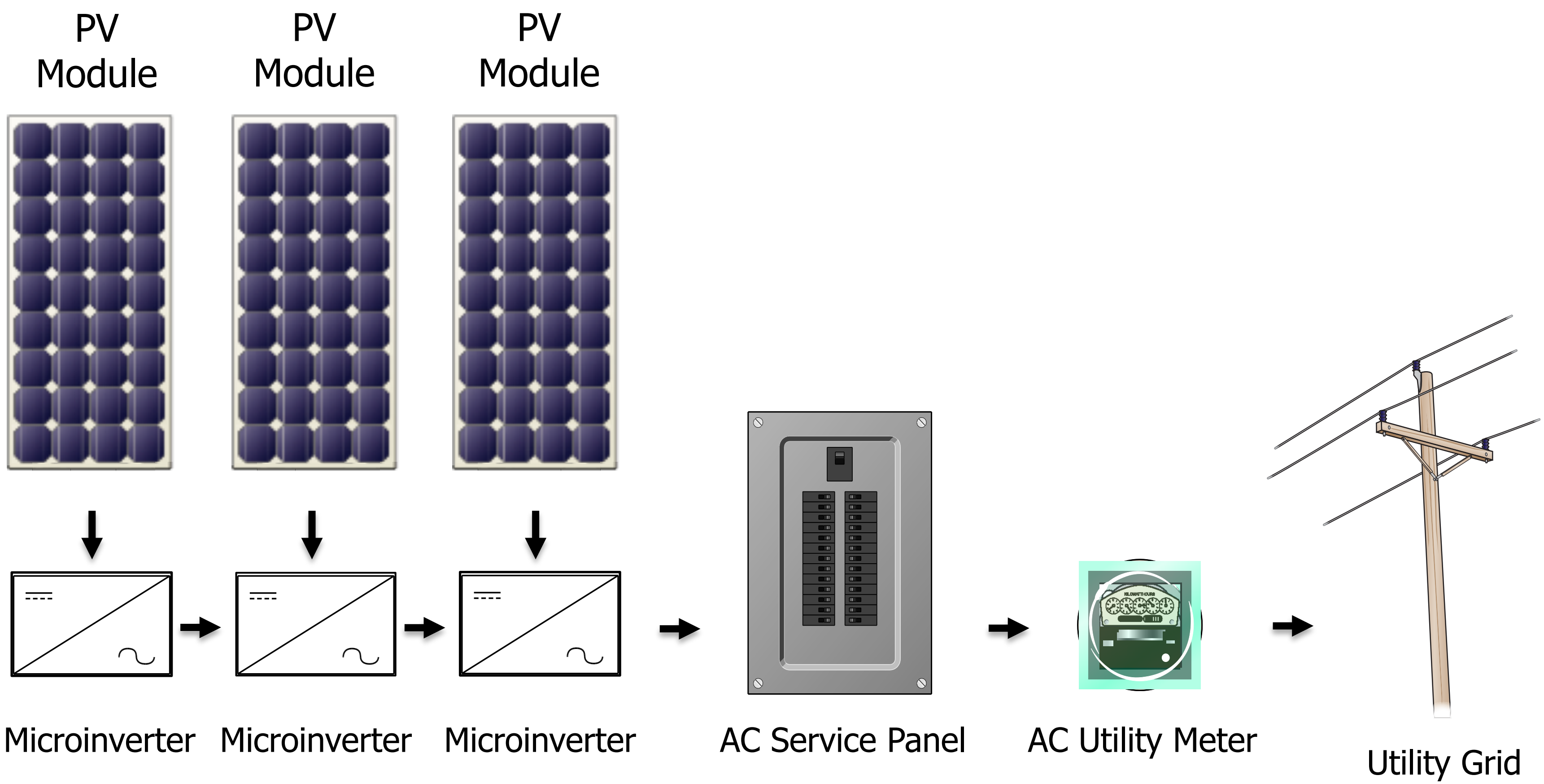
SOLAR ENERGY INTERNATIONAL

Grid-direct System



Grid voltage and frequency must be within limits of the inverter in order for it to synchronize with the grid

Grid-direct System with Microinverters

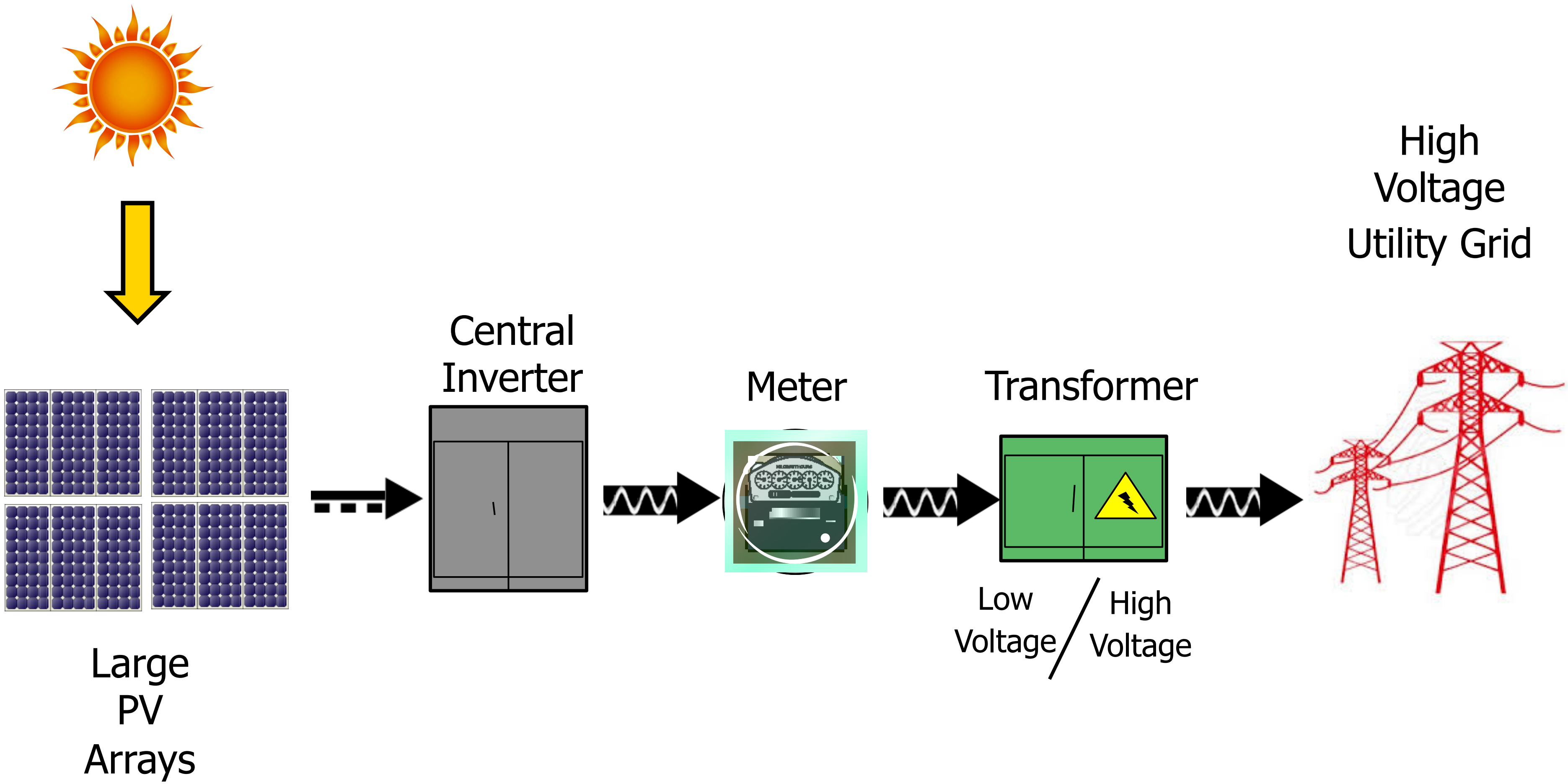


SOLAR ENERGY INTERNATIONAL

Grid-direct System Considerations

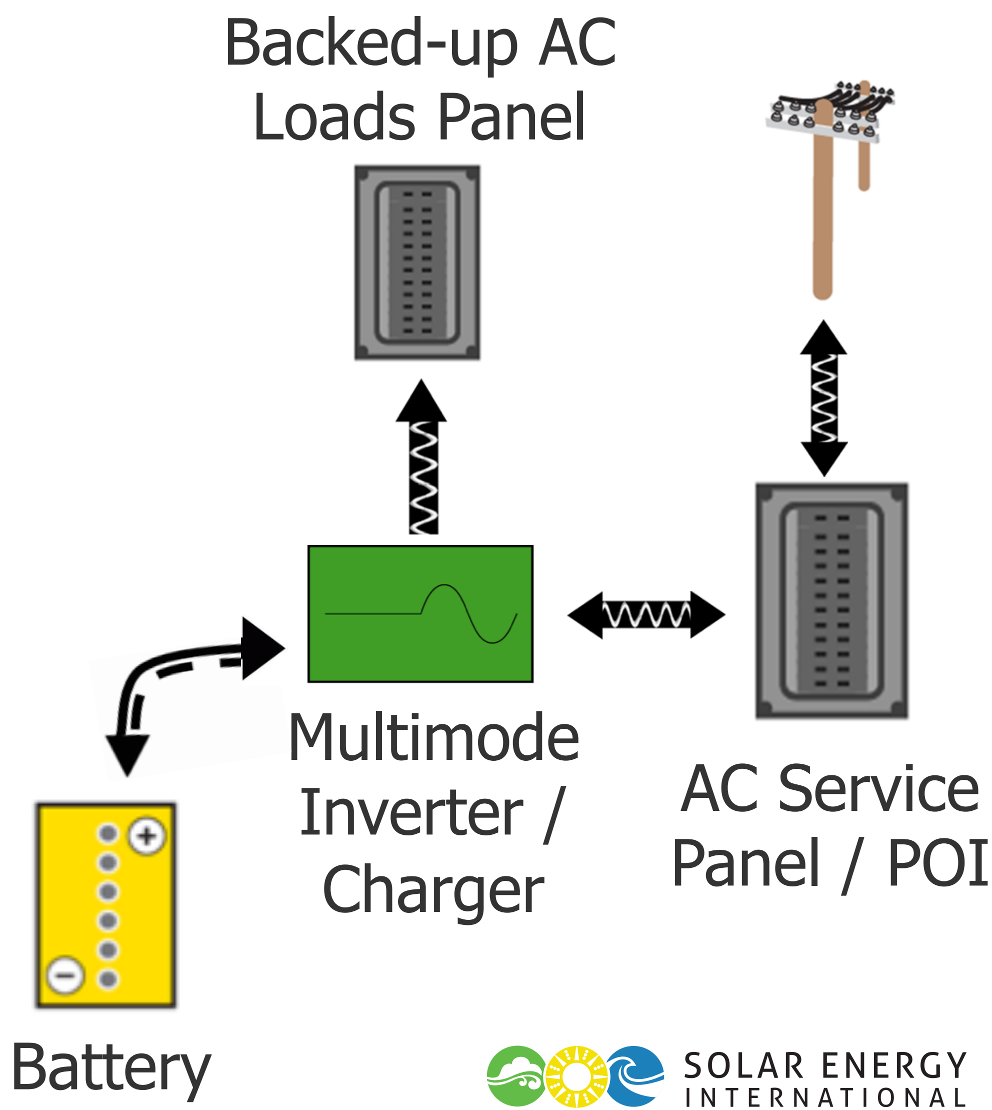
- Utility grid must be present for inverter to operate – no power when grid goes down
  - Inverter is a current source, not a voltage source – requires AC waveform from utility to sync with, will not operate without it
  - The grid provides energy "storage"
  - Grid supplements PV power to ensure all loads can operate
- As compared to battery-based systems
  - Fewer components, less complicated, easier to install
  - No batteries
  - Less expensive
  - Higher efficiency
  - Higher DC voltage

PV Power Plant



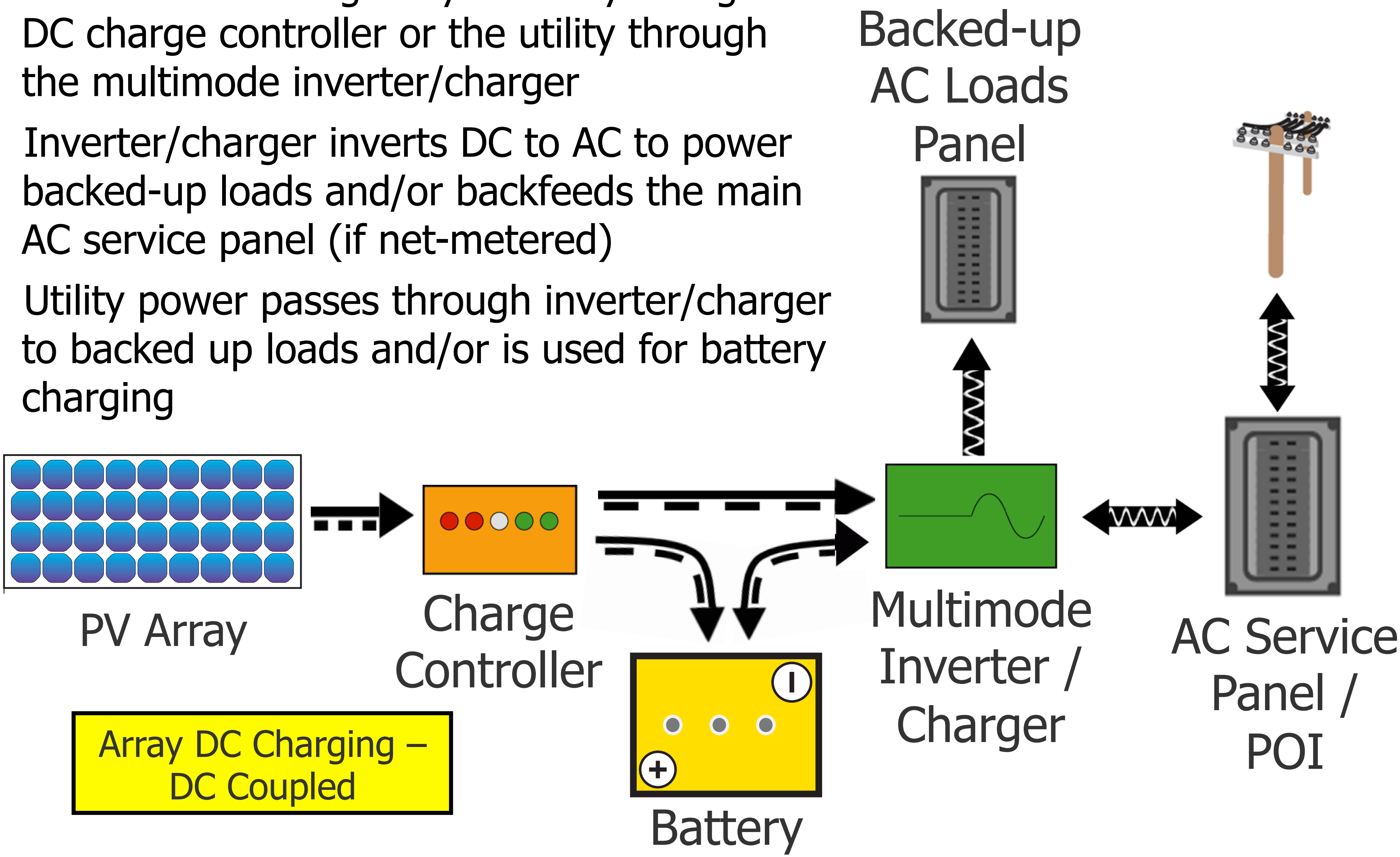
Multimode AC System: Battery Backup Only, No PV

- Batteries are normally kept at a full state of charge by using utility grid power
- System provides temporary power to backed-up loads during a utility outage
  - Can also function as peak load shaving or load shifting system
- No way to recharge batteries without the utility grid or generator

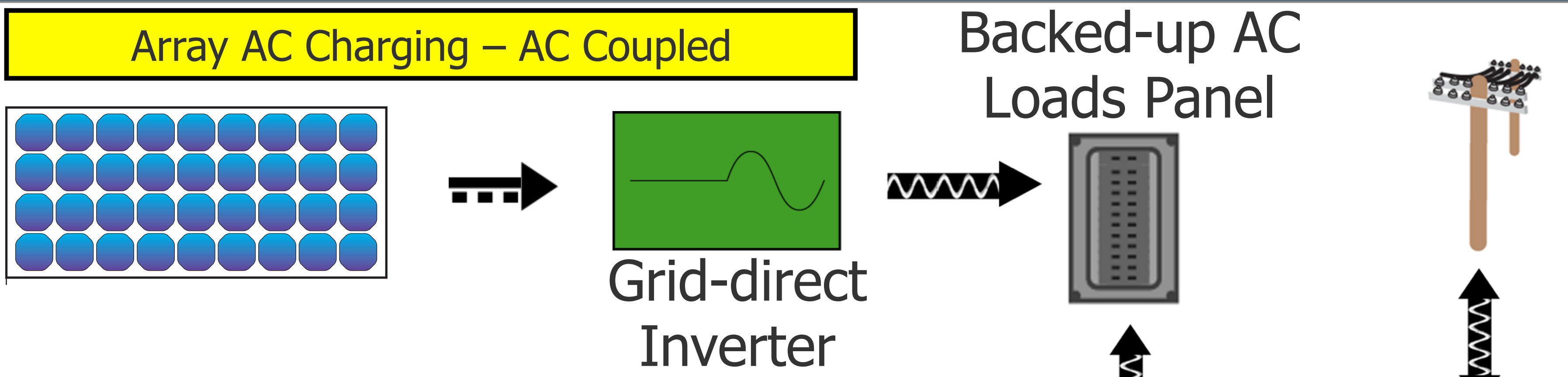


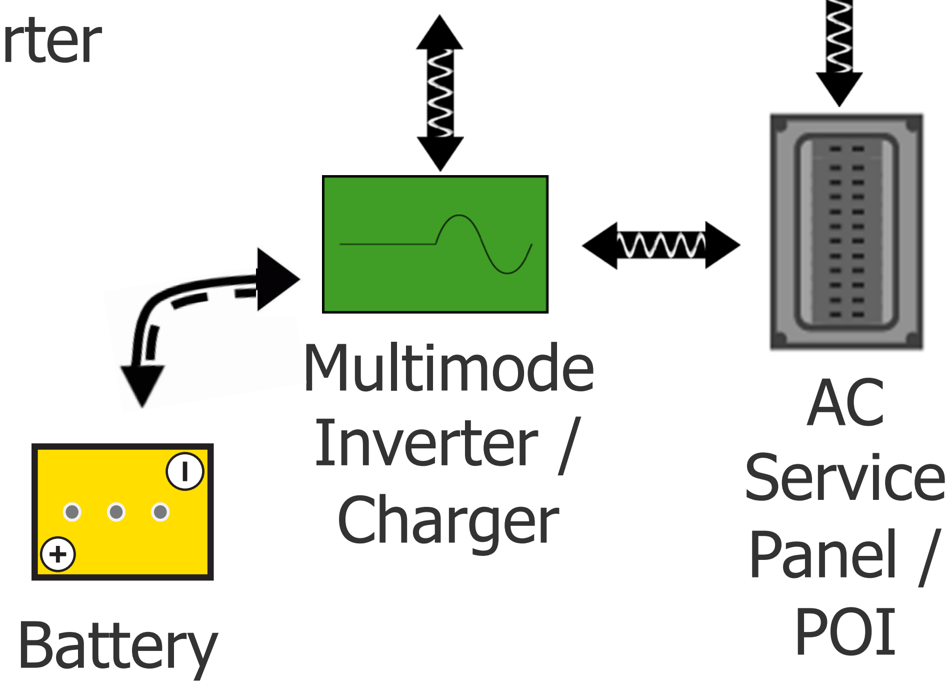
Multimode (Grid-tied with Battery Backup): DC PV Charging (DC Coupled)

- Batteries are charged by PV array though the DC charge controller or the utility through the multimode inverter/charger
- Inverter/charger inverts DC to AC to power backed-up loads and/or backfeeds the main AC service panel (if net-metered)
- Utility power passes through inverter/charger to backed up loads and/or is used for battery charging



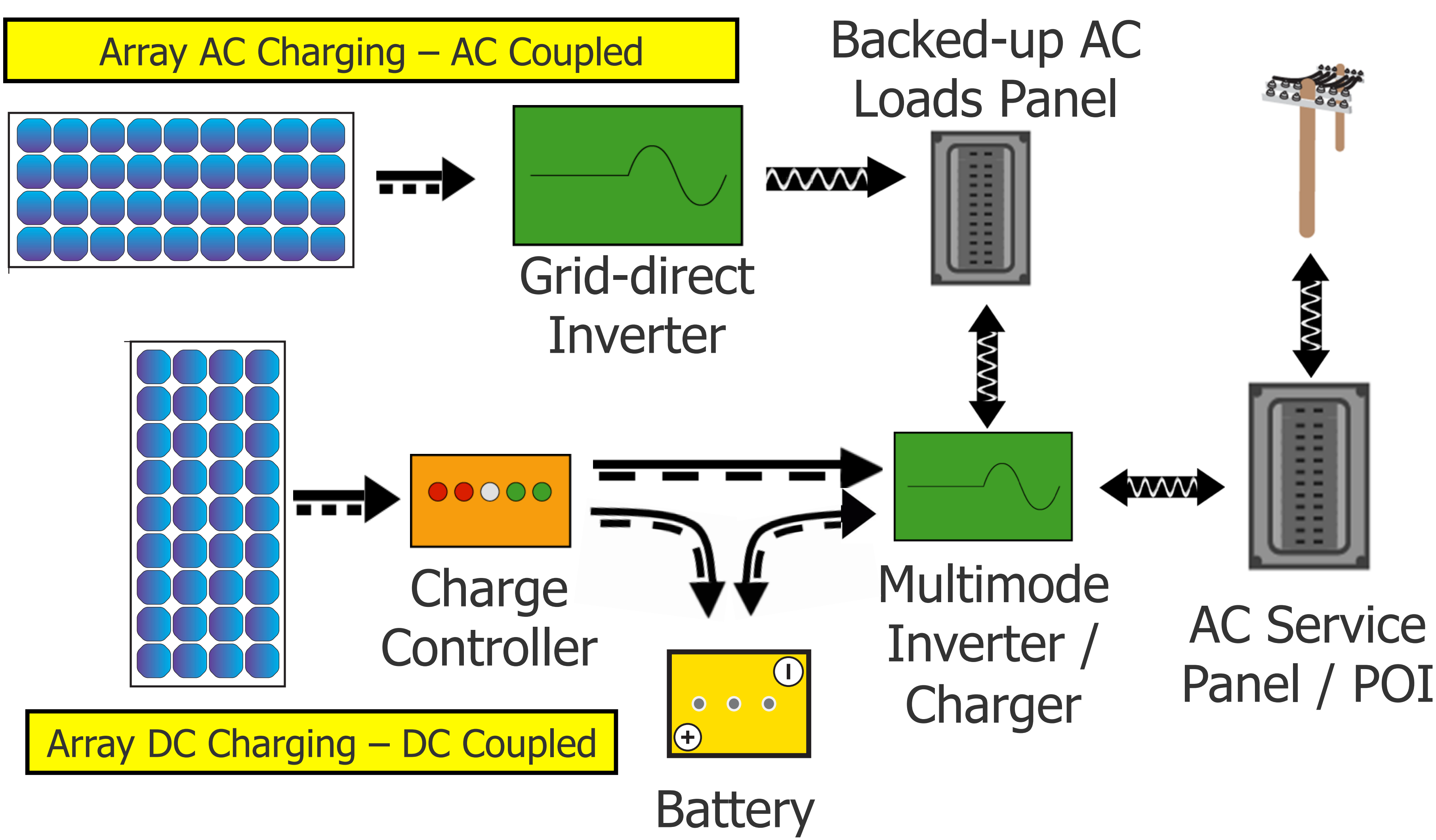
Multimode (Grid-tied with Battery Backup): AC PV Charging (AC Coupled)





- AC output breaker from grid-direct inverter is located in backed-up loads panel
- Inverter/charger processes PV generation or utility power to charge the batteries
- The inverter/charger feeds the AC service panel/POI from the batteries or PV array

Multimode (Grid-tied with Battery Backup): PV Charging - AC *and* DC Coupled



AC Coupling: Possible Advantages

- Efficient means of utilizing PV array output if AC loads are used during peak solar production hours
- Use of grid-direct inverter allows PV array to be wired at higher voltage, resulting in fewer parallel strings and combiners
  - Some high voltage charge controllers are available for DC coupled systems
- Microgrid applications
  - When buildings are far apart, AC power can be distributed easily using commonly available transmission equipment
- Add battery backup to existing grid-direct system using the grid-direct inverter plus a new multimode inverter

SOLAR ENERGY INTERNATIONAL

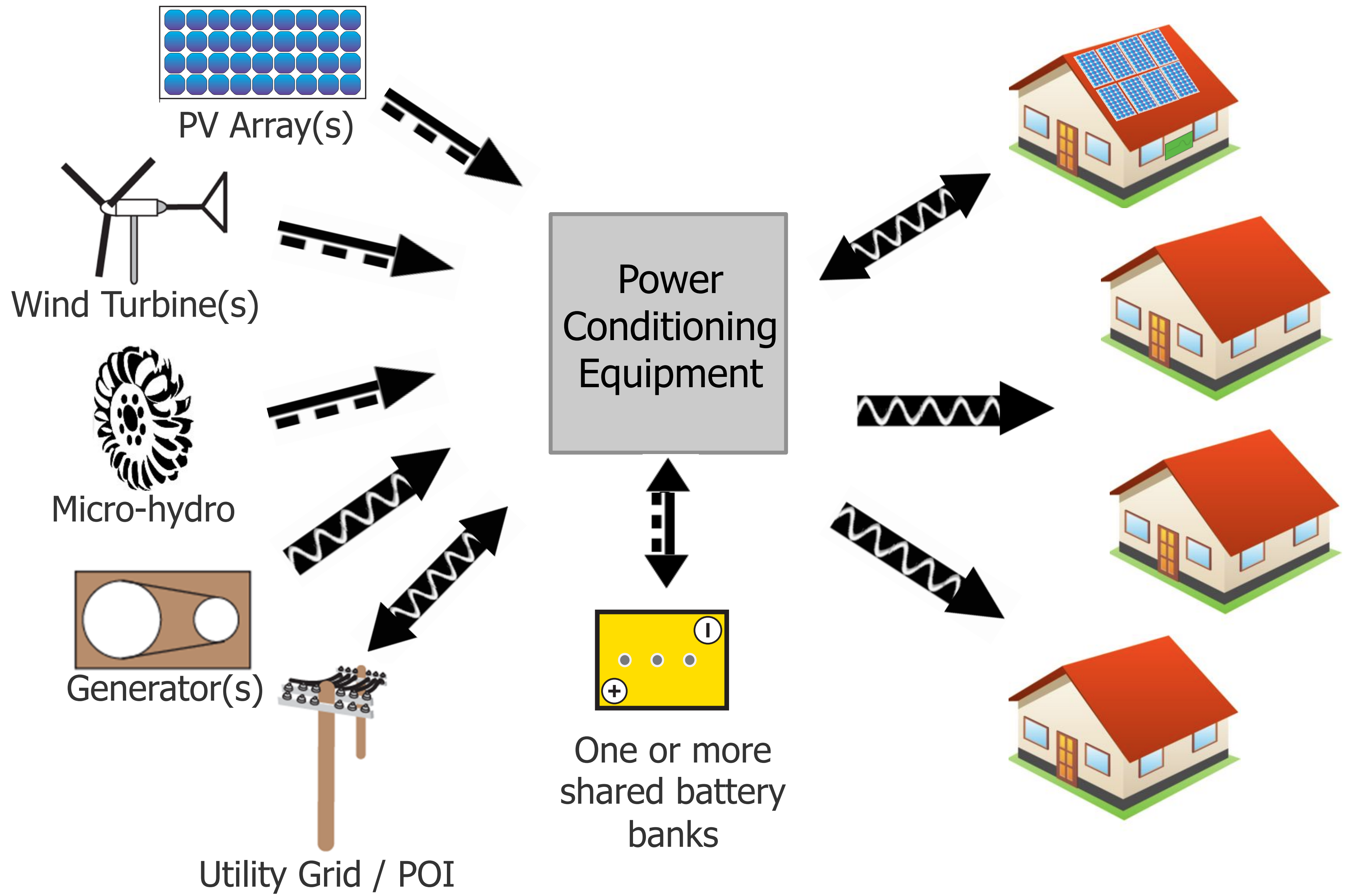
AC Coupling: Possible Disadvantages

- Blackout possibility during stand-alone operation if battery voltage hits multimode inverter LVD setting
- Some AC coupled systems utilize equipment from multiple manufacturers, adding complexity
  - Grid-direct inverter manufacturers may not support their product warranty in an AC coupled application
- May be cost prohibitive for smaller systems
- Many system designers and technicians have limited experience with battery-based systems and even fewer have experience with AC coupled systems

SOLAR ENERGY INTERNATIONAL

Microgrid System

Energy sources —— Energy storage and management —— Energy consumers



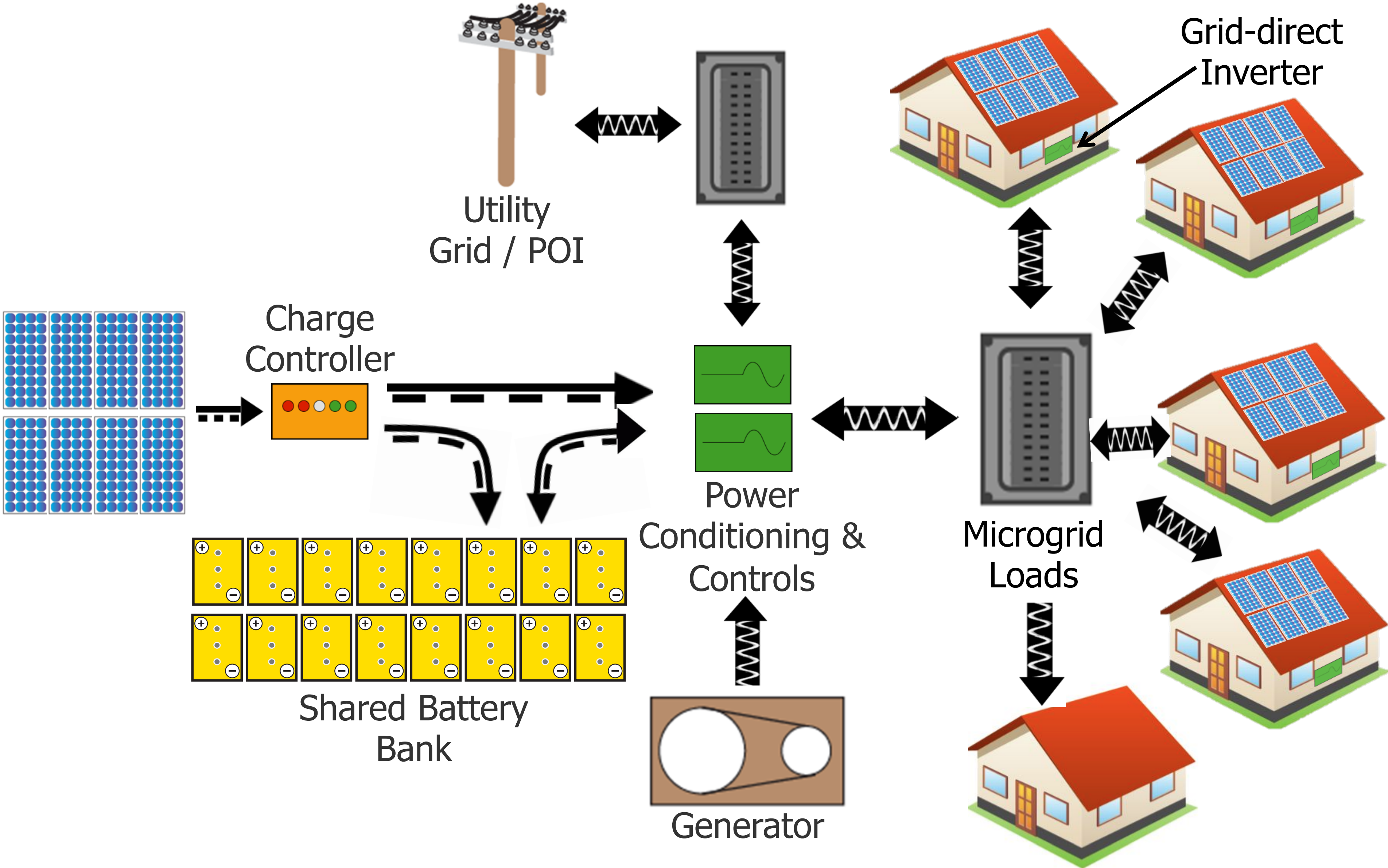
Microgrid: Definition and Categories

- There is no single, accepted definition of a microgrid
- SEI's definition:
  - A microgrid consists of interconnected power generation, energy storage, and loads shared by multiple buildings, sites, or services, all contained within a clearly defined electrical boundary. A microgrid may be grid connected (utility interactive), but has the ability to operate independently (islanded) when the utility grid is not present or not providing power.

Categories

- **Stand-alone microgrid:** not connected to utility grid
- **Multimode microgrid:** connected to utility grid, but can function in stand-alone mode without utility grid connection

Multimode Microgrid

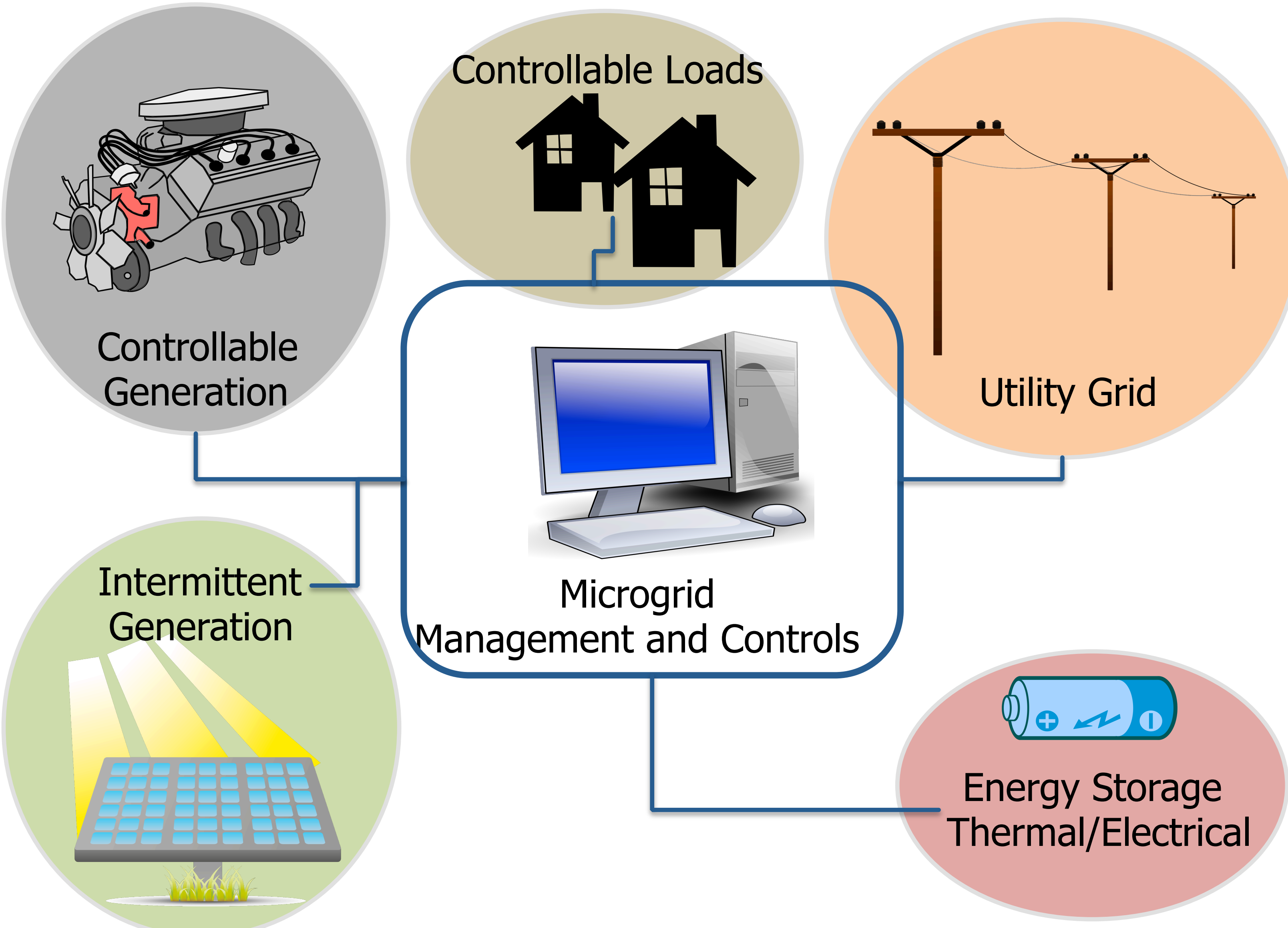


Going Big...Large Scale Microgrids

- Equipment and engineering specific for the project
  - Variations in application, scale, and complexity
- PV has not always been a part of large microgrids
  - Intermittent nature
  - Lack of control forecasting mechanisms
  - Historically higher cost
- Large volume storage and generation options
  - Most common is petroleum fuel
  - Other options include batteries, compressed air, fly wheels, and thermal mass (i.e. molten salt)

SOLAR ENERGY INTERNATIONAL

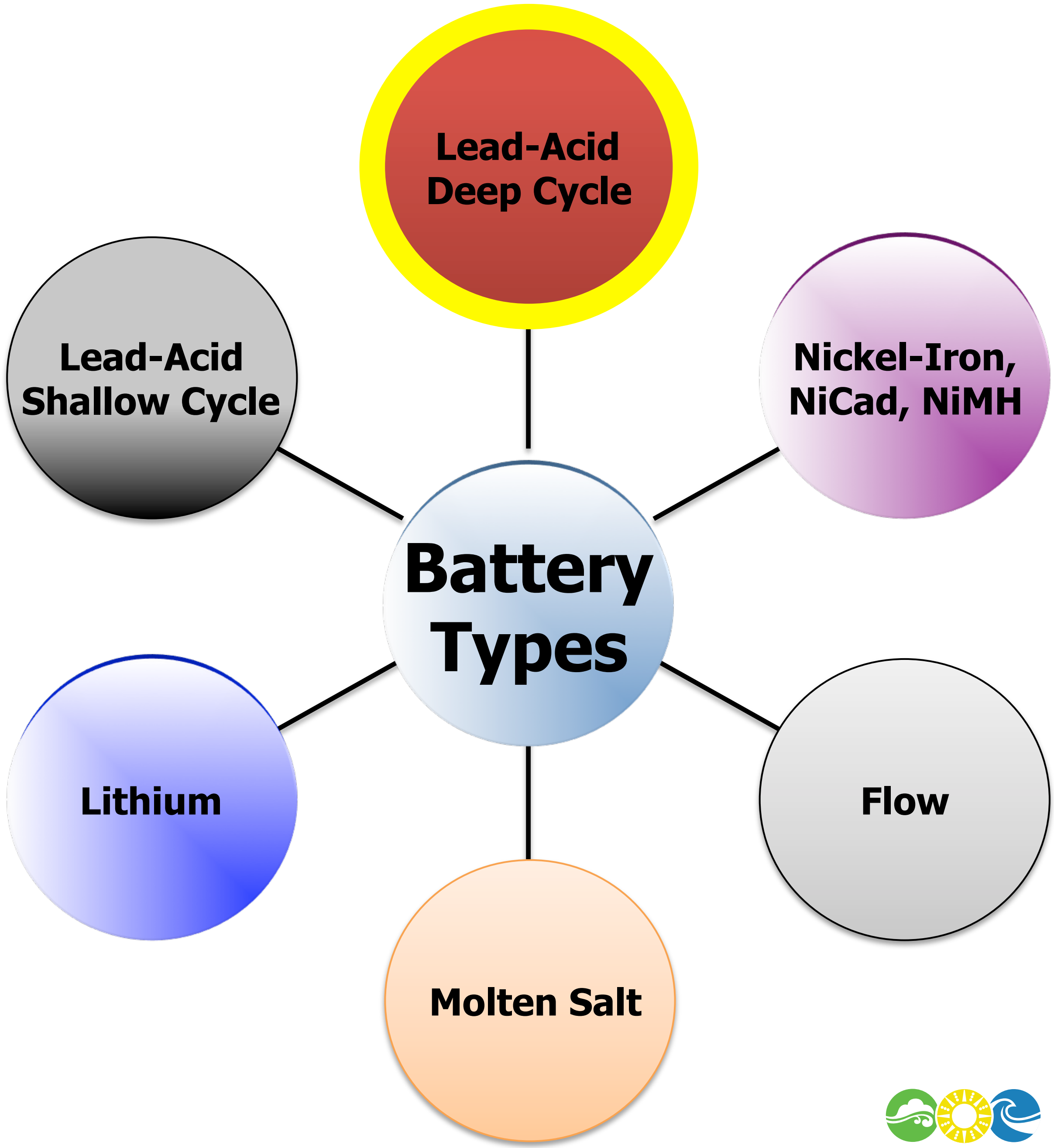
Going Big...Large Scale Microgrids



Benefits of Grid Connected Battery Storage

- Utility grid
  - Increase reliability and power quality
    - Stabilize voltage and frequency support
  - Time shifting RE generation
    - Deferral of building generation capacity and transmission and distribution upgrades, transmission congestion relief
  - Manage/smooth RE power fluctuation in high RE penetration areas
    - Curtailment and demand response are other options
    - Real-time load/power management based on weather forecasting and other variables
  - Load shedding and load shifting
- End users (industrial, commercial, residential)
  - Utility bill reduction through demand charge or time of use charge management
  - Back up power

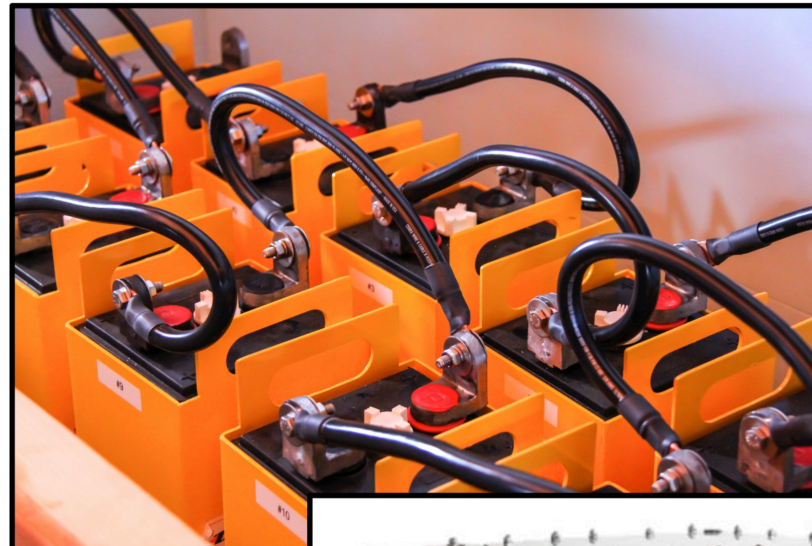
SOLAR ENERGY INTERNATIONAL



SOLAR ENERGY INTERNATIONAL

Comparing Battery Technologies

- Cost
  - Upfront vs. cost per kWh
- Longevity and cycle life
  - Maintenance
- Self-discharge rate
- Battery Management System (BMS) required?
- Durability and resilience to deep discharges
- Temperature range
  - Do high or low temperatures cause damage?



Comparing Battery Technologies

- Net efficiency
  - Power in vs power out
- Specific energy (energy density)
  - Battery capacity by weight or size (Wh/kg)
- Equipment compatibility
- Discharge rate limits
- Safety
- Toxicity
- Recyclability?

Photo: West Marine

Courtesy: Sunsense Solar

Courtesy: Iron Edison

Snapshot Cost Comparison

	Lead Acid Flooded	*Lead Acid VRLA*	*Sodium Ion*	*Lithium Iron Phosphate*	*Lithium Ion "Powerwall"*	*Nickel Iron*
Cycle life to 80% DOD	1,000 cycles	500 cycles	3,000 cycles	3,000 cycles or more	3,000 cycles	11,000 cycles
Efficiency	85%	88%	90% low rate, 75% at high	90%	92%	75%
Upfront cost	\$158/kWh	\$225/kWh	\$510/kWh	\$489/kWh	\$420/kWh	\$792/ kWh
Energy cost over cycle life	21.5¢/kWh	57.5¢/ kWh	21.8¢/kWh *(42.4¢/kWh w/current inverters)*	21.5¢/ kWh	18¢/kWh	12.3¢/ kWh

Prices and efficiency subject to change

Microgrid Non-technical Considerations

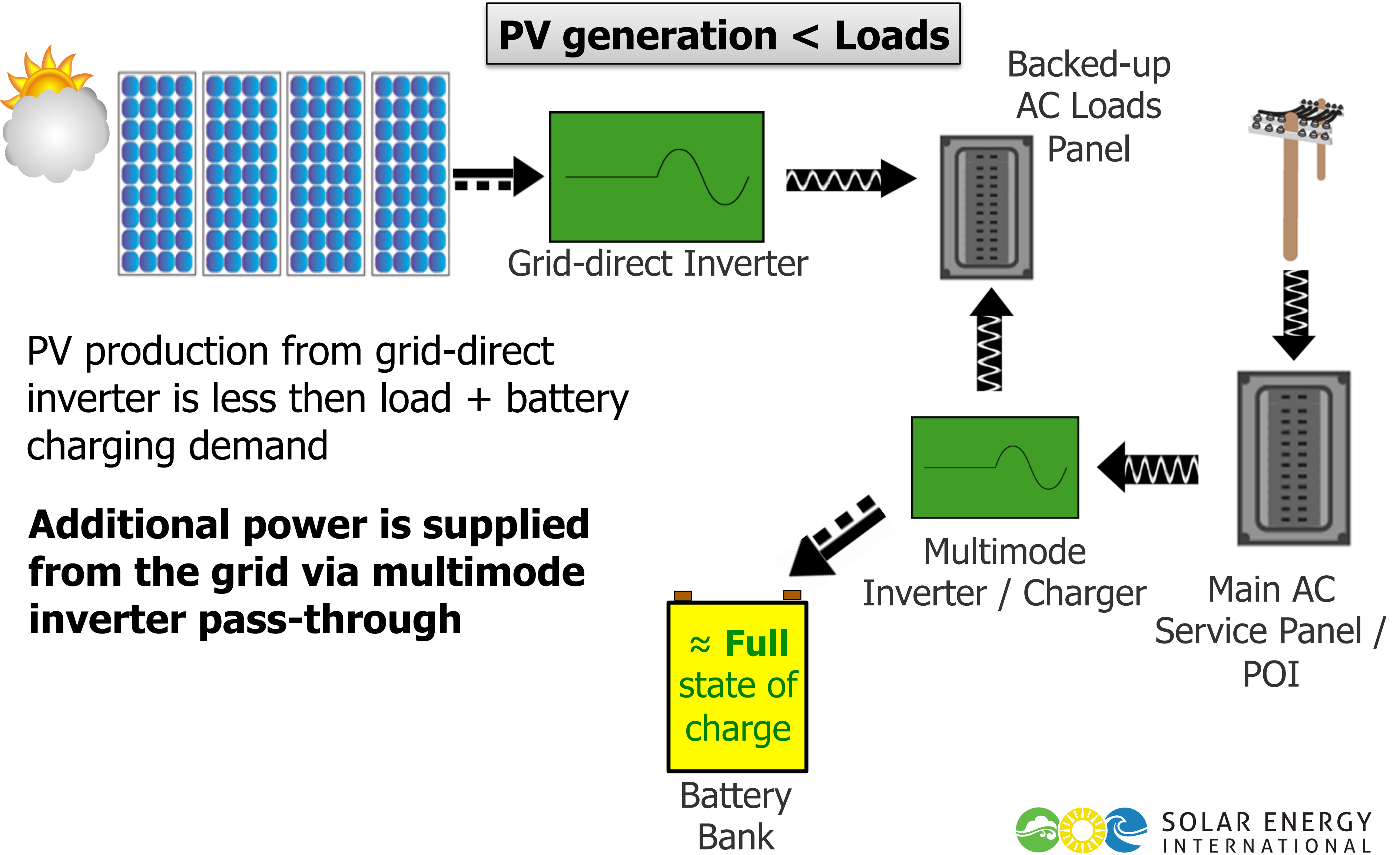
- Government / utility policy & regulations
- Expectations of the system users / owners
  - Differences between stand-alone and multimode
- Financing & risk management
- End-user training and orientation
  - Payment collection if applicable
- Maintenance costs & plans
  - Maintenance technician training

SOLAR ENERGY INTERNATIONAL

PV GENERATION < LOADS

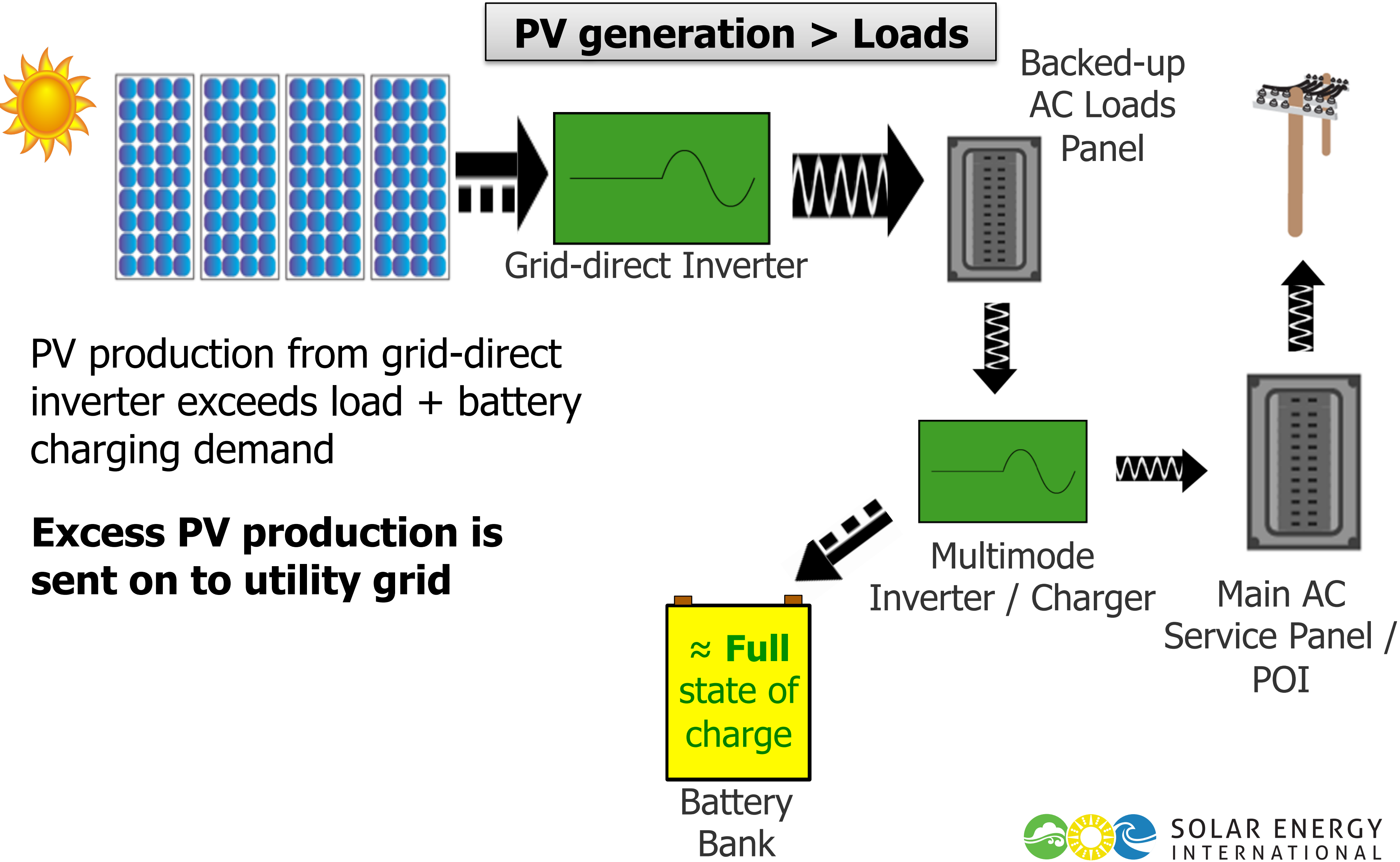
PV production from grid-direct inverter is less then load + battery charging demand

Additional power is supplied from the grid via multimode inverter pass-through



Multimode system example

PV Generation > Loads

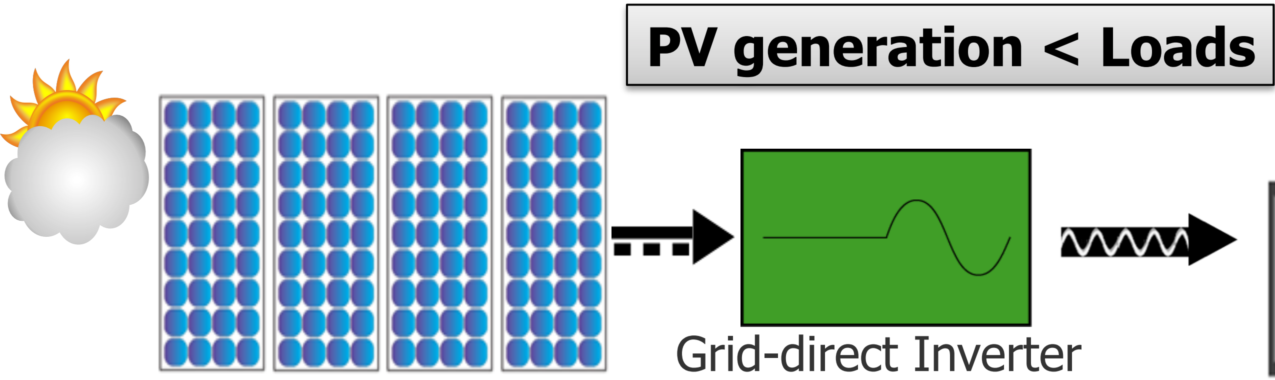


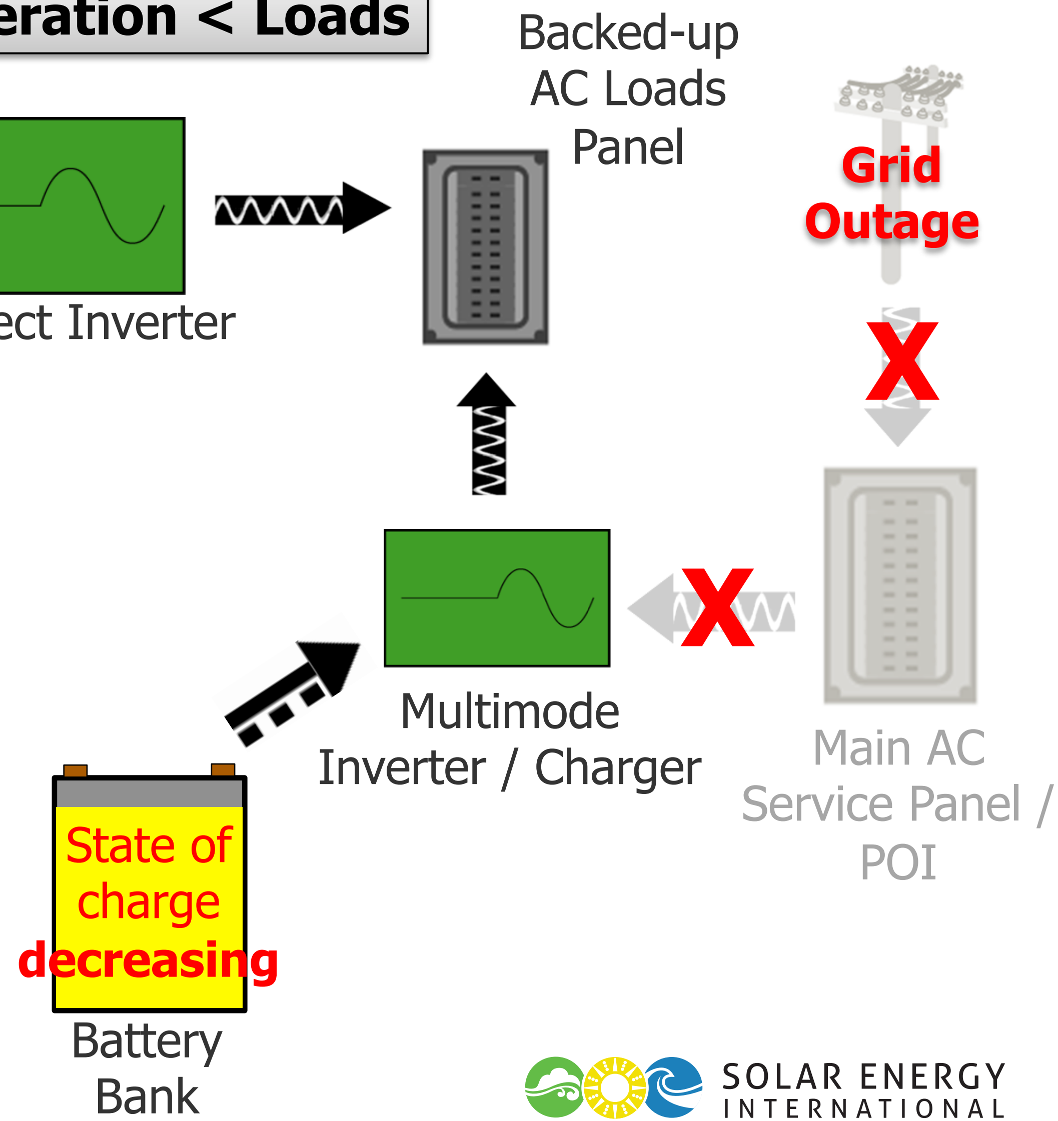
PV production from grid-direct inverter exceeds load + battery charging demand

Excess PV production is sent on to utility grid

Multimode system example

PV Generation < Loads, Grid Outage





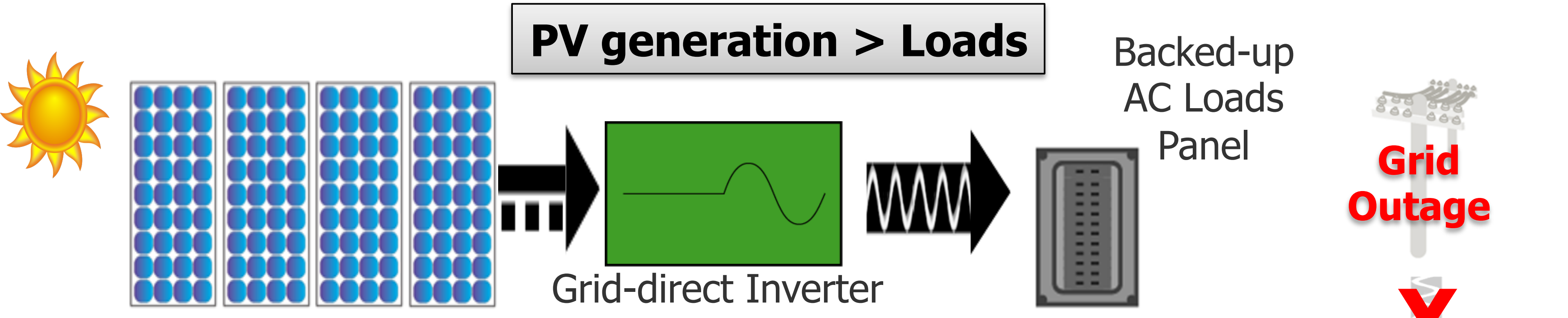
No utility grid; PV production from grid-direct inverter is less then load demand

Battery bank provides additional power to meet demand

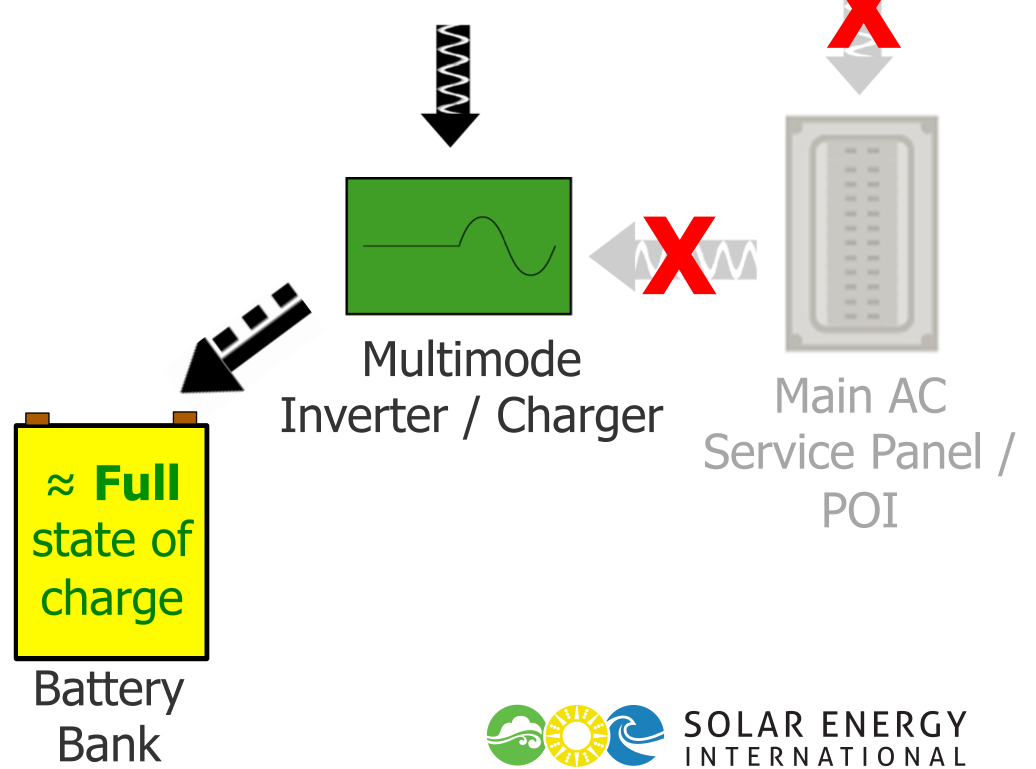
Situation can occur in stand-alone and multimode systems

SOLAR ENERGY INTERNATIONAL

PV Generation > Loads, Grid Outage



No utility grid; PV production from grid-direct inverter exceeds load + battery charging demand



Excess PV production needs to be regulated to prevent battery overcharging!

Situation can occur in stand-alone and multimode systems

SOLAR ENERGY INTERNATIONAL

PV Output Regulation:
When batteries are full and loads do not need all the power

DC coupled PV

- DC charge controller regulates PV through three-stage charging

AC coupled PV

- No DC charge controller to regulate battery charging
- Output of grid-direct inverter must be regulated
- Regulation method depends on application and equipment manufacturer recommendations/requirements

AC coupled PV regulation methods

- Relay control
  - Relay installed for "on/off" regulation of grid-direct inverter
- Diversion control
  - Diversion load consumes excess power
- Frequency shift
  - Frequency modification for "on/off" regulation
- Frequency shift

OEMs that Support AC Coupling

Schneider
www.schneider.com

MAGNUM
www.magnumenergy.com

SMA
www.sma-america.com

OUTBACK
www.outbackpower.com

Microgrid applications with large power requirements will likely require equipment that is custom-built and engineered specifically for the application. Not all companies that support AC coupled applications are listed here. New equipment is arriving and the market can change quickly.

ABB

SIEMENS

AC Coupled Inverter Considerations

- Are grid-direct inverter and inverter/charger from the same manufacturer?
- Does the manufacturer(s) support AC coupling applications?
  - Important to maintain equipment warranty
- What method does the manufacturer recommend for grid-direct inverter power regulation?
  - Frequency shift, relay, diversion load, or a combination
  - Is power regulation method suitable for system application?
- AC voltage
  - May require additional equipment if grid-direct inverter AC voltage does not match load inverter/charger
  - Example: 120 VAC multimode inverter, 240 VAC grid-direct inverter
- Scalability
  - How many units can be stacked (output connected in parallel)?
  - Separate battery banks and services or larger inverter/charger?

Grid-direct to Inverter/Charger Power Ratio

- Often limited to rated power capacity of inverter/charger or current rating of internal AC transfer switch, whichever is less
- Ratio may be different for multimode vs. stand-alone applications

Note: Consult manufacturer to confirm specific limitations and current specifications

Manufacturer / model	Recommended grid-direct to inverter/charger max ratio	Inverter/ charger max pass through rating	AC coupled grid-direct inverter regulation methods
Magnum Energy (MSPAE models)	0.9 : 1	30 A	AC diversion load controller and frequency shift
Outback (GS8048)	0.75 : 1	50 A	Relay controlled
Schneider (XW models)	1 : 1	60 A*	Frequency shift and/or relay controlled; frequency shift communication (off-grid only)
SMA America (Sunny Island models)	2 : 1 (off-grid) 1 : 1 (multimode)	56 A	Frequency shift communication w/ compatible SMA grid-direct inverters

**Maximum pass though rating does not increase with inverter parallel stacking on Schneider XW models*

How do the batteries get charged if the inverter/charger shuts down?

- Inverter/charger does not self-restart when shut down due to low battery voltage
- If AC voltage is not provided to grid-direct inverter, it will not turn on to charge the batteries
- Solutions
  - Load shedding
    - Some (or all) loads turn off as battery state of charge is depleted to avoid complete inverter/charger shut down
  - Add DC coupled PV system as backup
    - Charge controllers work independently
    - Good design practice for stand-alone applications

SOLAR ENERGY INTERNATIONAL

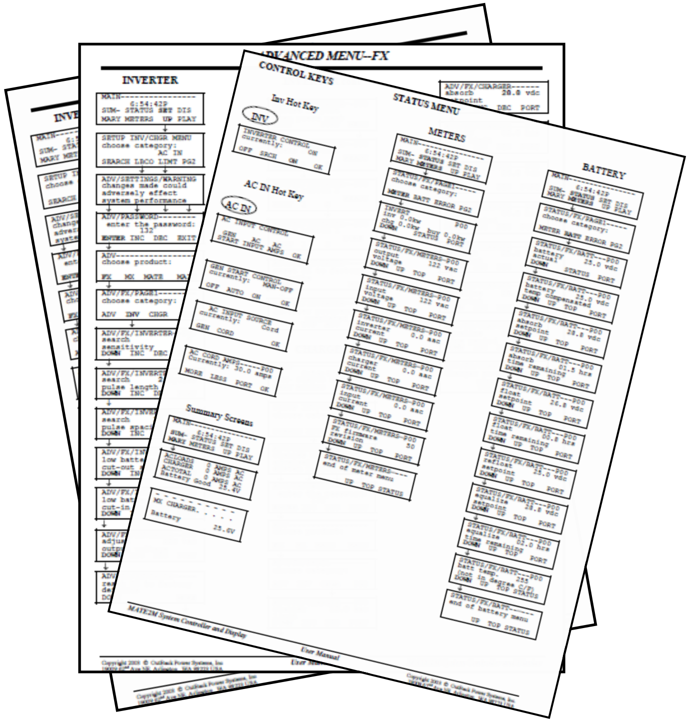
Generator Integration

- System must never allow grid-direct inverter to feed power into the generator!
- Bypass switch
  - Design error can lead to generator back-feed when system is in bypass position
- Most equipment requires that the grid-direct inverters are isolated when generator is running*
- Possible solutions
  - Install relay on grid-direct inverter output – opens when generator turns on to isolate from system
  - Install inverter breaker(s) in separate sub-panel that is isolated when bypass transfer switch is activated

** SMA Sunny Island is an exception. Reverse current setting is used. If SI unit detects reverse current to generator above set point, the generator is disconnected.*

Programming Required!

- Many set points and programing details
  - Depends on equipment manufacturer recommendations, system type, and application
- Programming parameters for AC coupled systems may include
  - Relay set points
  - Auxiliary output set points
  - Diversion load controls
  - AC coupled mode
  - Firmware updates
- Read all manuals and consult equipment manufacturers



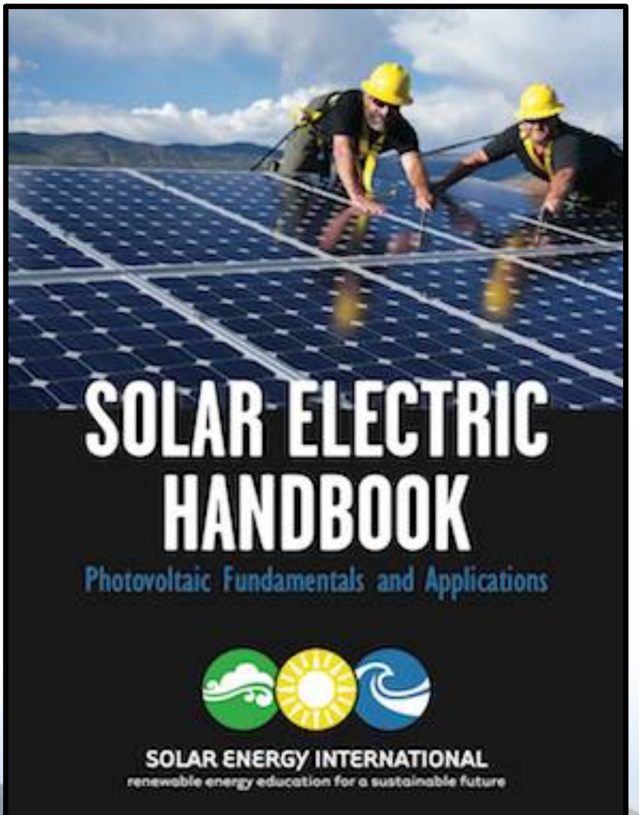
Courtesy: Outback Power

Each OEM and system application has unique programming requirements!

Thanks from SEI!

For more training, including in-person, online, hands-on, or customized for your company or organization, visit:

www.solarenergy.org



SOLAR ENERGY INTERNATIONAL

SEI Professional Services

For a World Powered by Solar Energy

PASSION FOR SOLAR POWER IS WHAT INSPIRES US

Made up of SEI instructors and alumni.

DESIGNING, INSPECTING AND COMMISSIONING ARE OUR SPECIALITES

Do you want the best in the industry assuring quality on your next project? Look no further.

PROVIDING THE HIGHEST QUALITY TECHNICAL SERVICES TO THE SOLAR INDUSTRY IS OUR BUSINESS

The highest integrity design and third-party services are only a phone call or email away.

www.seisolarpros.com

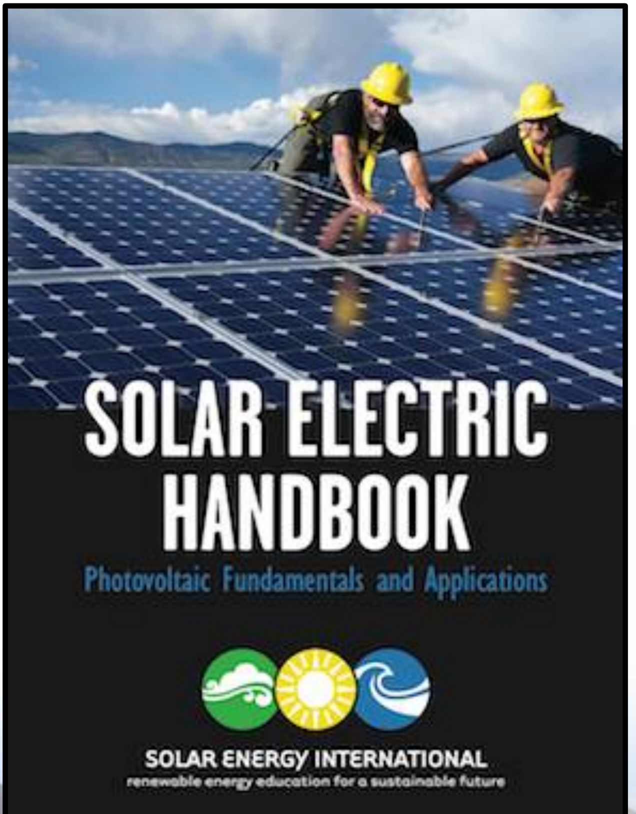
(970) 527-3920

SOLAR ENERGY INTERNATIONAL

Thanks from SEI!

For more training, including in-person, online, hands-on, or customized for your company or organization, visit:

www.solarenergy.org



SOLAR ENERGY INTERNATIONAL