Technology Tips for Solar + Storage REAP Application Reviews

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National Renewable Energy Laboratory
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July 17, 2024

NREL/PR-7A40-90582

Agenda

1 **Solar + Storage 101 (11:00-11:30 MST/1:00-1:30 EST)**
Tony Jimenez, National Renewable Energy Laboratory

2 **Solar + Storage Applications for REAP (11:30-12:00 MST/1:30-2:00 EST)**
Bharat Solanki, National Renewable Energy Laboratory

- **Please feel free to put your questions in the chat.**
- **We will address questions during and after the presentation, and we will also follow up afterwards if needed.**

The following information and best practices are recommendations based on NREL's experience in this area and are not meant to supplant any REAP application requirements.

NREL staff can not answer any application-specific questions. These should be directed to REAP program staff.

Other USDA/NREL Events

- **USDA REAP Funding for Your Distributed Wind Energy Project (for applicants)**
  - **June 17th, 11-12:30 MST**
  - **Register [here]**

- **Technology Tips for REAP Application Reviews: Distributed Wind (for USDA staff)**
  - **June 18th, 11-12 MST**
  - **Register [here]**

- **USDA REAP Funding for Your Solar + Storage Project (for applicants)**
  - **July 17th, 1-2:30 MST**
  - **Register [here]**

Preliminaries: Energy vs. Power

ENERGY

Definition: the ability to do work

Energy is a quantity (akin to distance)

Equation: ENERGY = POWER x TIME

Typical units: Joule, kWh, BTU

POWER

Definition: Rate at which energy is being created, moved, or used

Power is a rate (akin to velocity)

Equation: POWER = ENERGY / TIME

Typical units: kW, BTU/hour, hp

Energy equipment items (e.g. generators, boilers, switches) are typically rated in terms of their peak power. (E.g., 100 kW generator, 5 hp motor).

Solar 101

Solar Resource: Definitions

Irradiance (power/area): Incoming solar power flux. Typical peak value of irradiance [midday in the summer in a sunny area] is ~ 1 kW/m^2).

Insolation/Irradiation (energy/area): The integral of the irradiance over a given time period. Typical average daily insolation on a horizontal surface in Colorado is ~ 4.9 kWh/m^2. The unit kWh/m^2 is sometime called a “sun-hour”.

Resource: Irradiance Components

Plane-of-Array = **Direct** x Cos (I) + **Diffuse + Reflected**

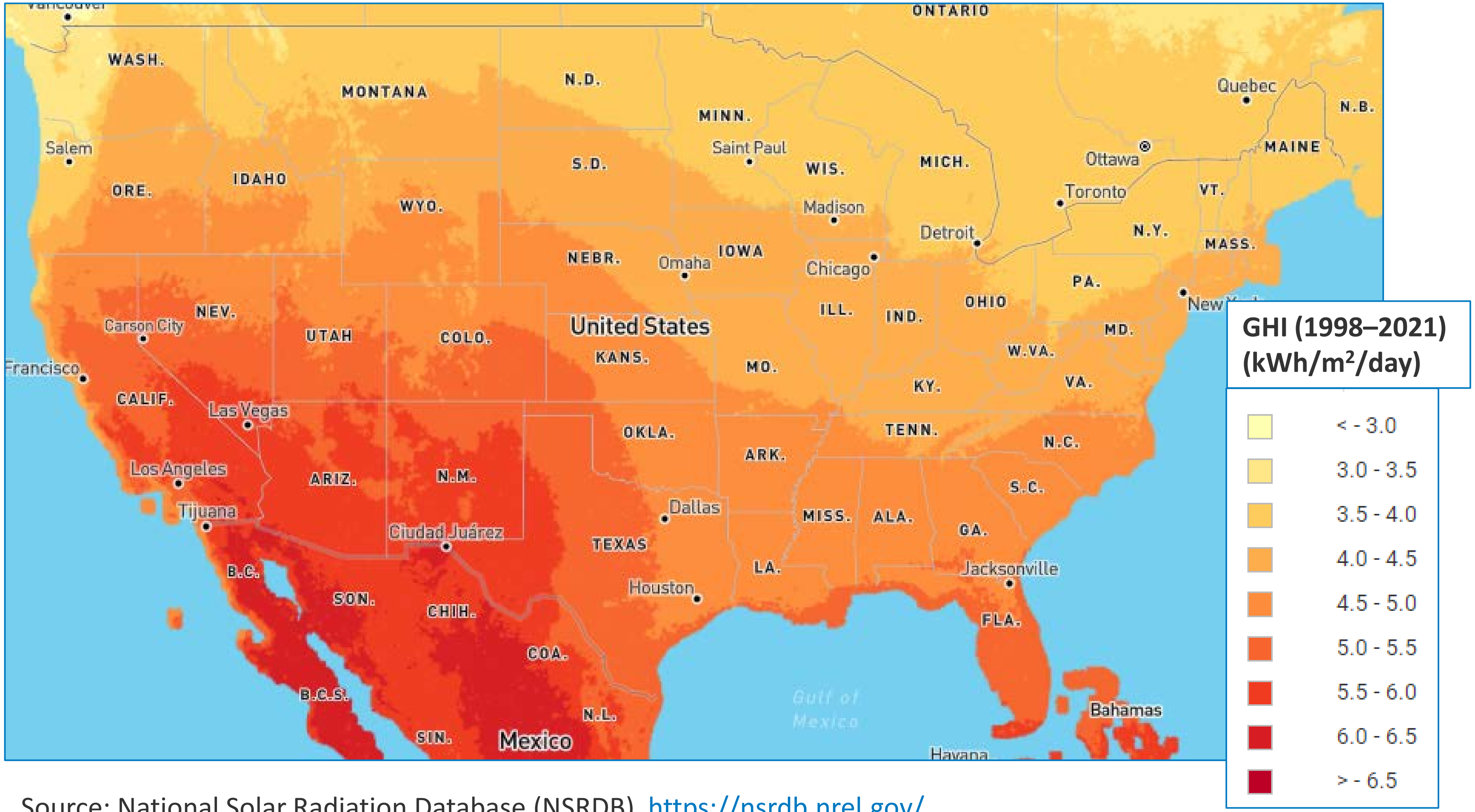
I = Solar Incidence Angle

Direct Normal "Beam"

Diffuse "Sky"

Total Hemispheric on *Horizontal* Surface "**Global**"

Solar Resource: Global Horizontal Irradiance (GHI)



Source: National Solar Radiation Database (NSRDB), https://nsrdb.nrel.gov/

Resource: Panel Orientation

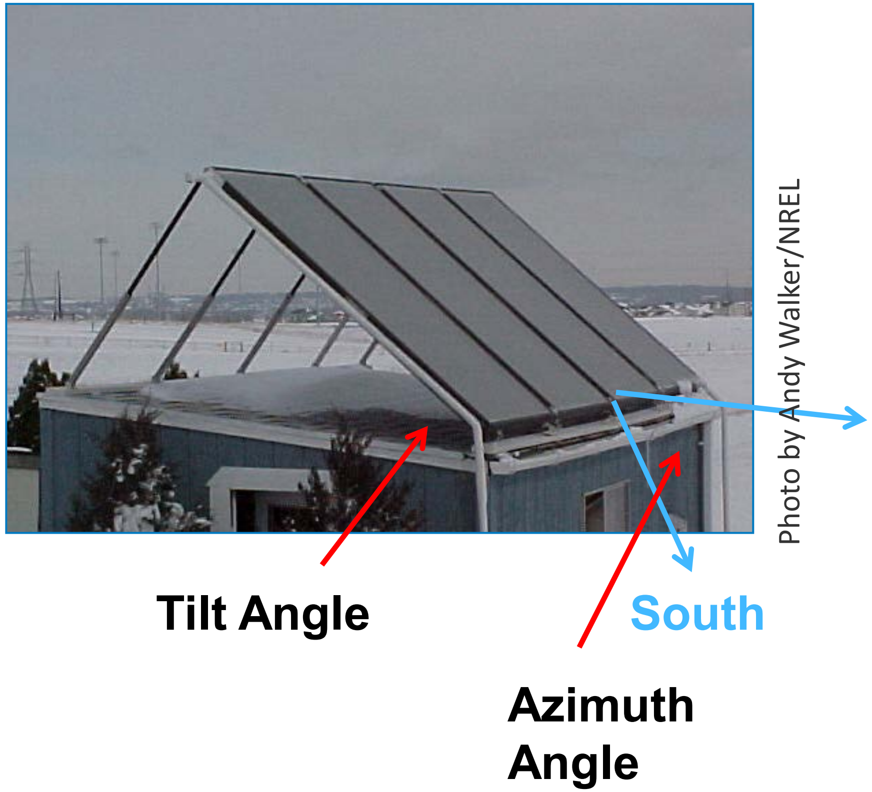
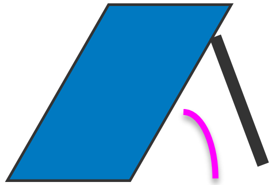


Photo by Andy Walker/NREL

Azimuth: Angle between the horizontal component of the normal to plane surface and due south

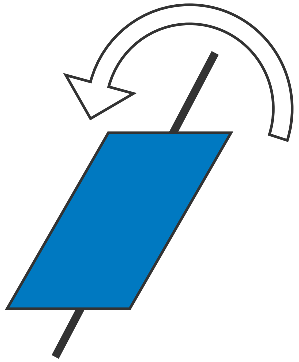
Tilt: Angle between the panel surface and the ground.

Solar Resource: Tracking

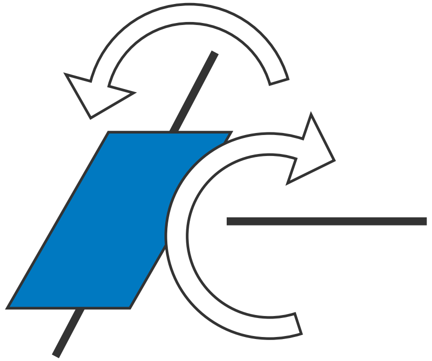


Fixed Tilt (facing Equator)

- tilt = latitude for max production
- tilt < latitude for summer gain
- tilt > latitude for winter gain



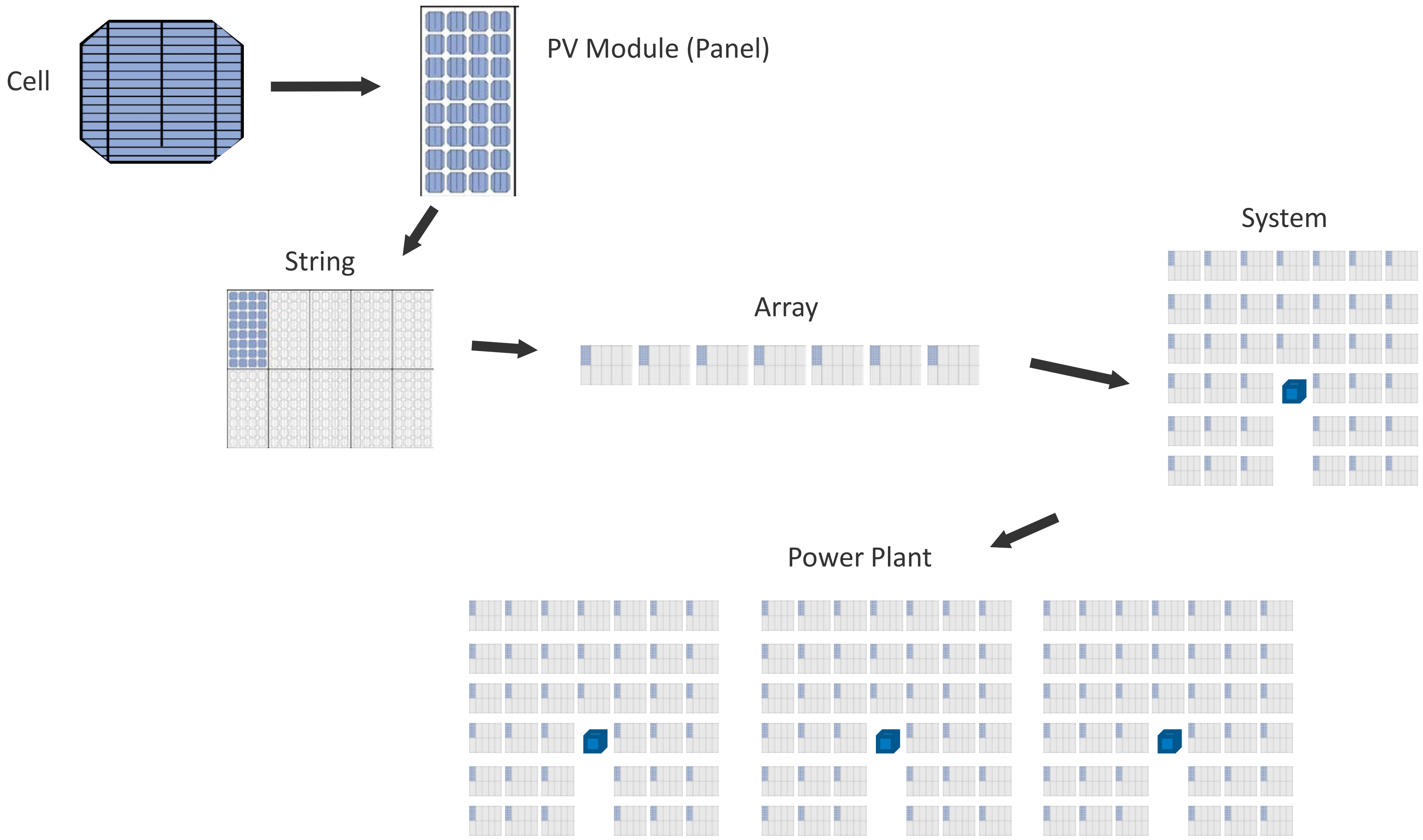
One Axis Tracking



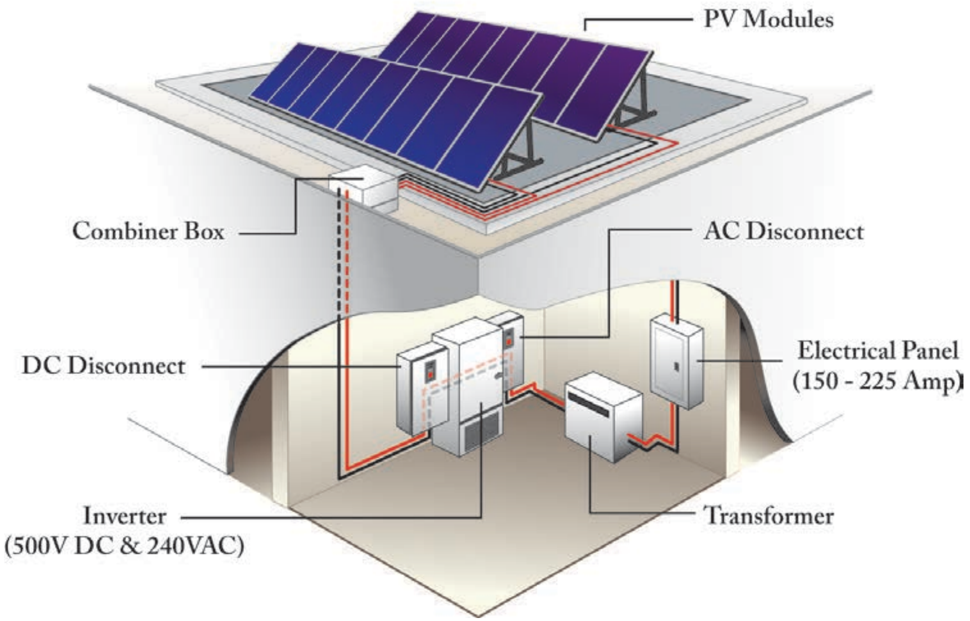
Two Axis Tracking

NREL Image Gallery #04827

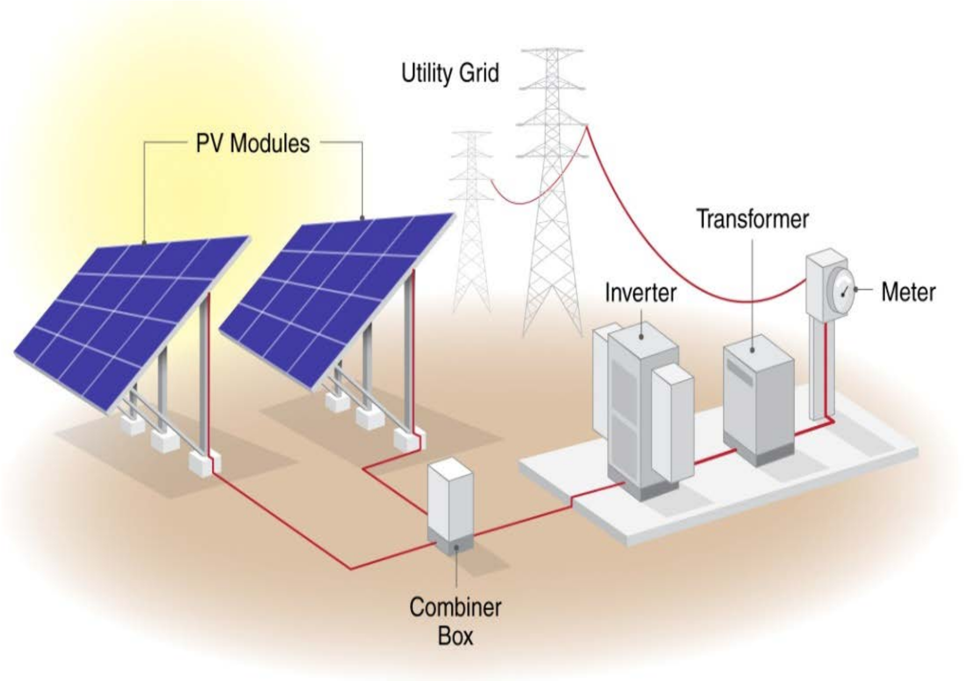
PV is Modular – Build System to Size Needed



Solar Technology (PV): System Components



Roof
Image by Jim Leyshon/NREL



Ground Mount
Image by Jim Leyshon/NREL

NOTE: Smaller systems many not have every component.

Solar Technology (PV): Overview

- Direct conversion of sunlight into DC electricity.
- Solid-state electronics, no-moving parts. Typical panel warrantee is 25 years.

- Panel Efficiency: 12% - 24%
- Panel rating given in Watts_{DC} (what the panel produces when receiving 1.0 kW/m^2 of incident radiation). Array capacity is the sum of the panel capacities.
- PV modules are wired in series, “strings” to meet the desired voltage.
- Strings are wired in parallel to achieve the desired energy production.
- DC converted to AC by the inverter. Inverter options include central, string, microinverter

- System rating described by both the array rating (kW_{DC} or MW_{DC}) and the inverter rating (kW_{AC} or MW_{AC}).
- For residential-size systems, AC rating ~= DC rating.
- For larger systems, DC rating is typically 20%-50% larger than the AC rating (Inverter Load Ratio [ILR] of 1.2 – 1.5).

Solar Technology (PV): Estimating Energy Production

Estimating Energy Production

- (Gross production) Multiply array rating (kW [per kW/m^2]) by insolation on the array (kWh/m^2)
- (Net production) Overall System losses (Array => inverter output): ~ 20%
    - Soiling, shading, mismatch, wiring, inverter, degradation, etc.
- Example: A 3-kW array receiving 5 kWh/m^2/day) would produce roughly 12.0 kWh per day.
    - (3 kW / [per kW/m2] * 5 kWh/m2/day * 0.80) = 12.0 kWh/day

- If lacking any information on the insolation on the array, use the global horizontal irradiance (GHI). (The increased production from tilting/tracking roughly offsets the system losses)

Solar Technology (PV): Planning Factors

Area Requirements

Roof Mounted (non-flat roof)

- ~15 watts (0.015 kW) per square foot of panel surface
- Assume can cover up to 50%-70% of roof surface

Ground Mounted

Need to distinguish between “array area” and “site area”.

Array area is generally in the range 3-4 acres per MW_{DC} .

- Fixed tilt systems are towards the lower end of range (higher density)
- Tracking systems are towards the higher end of the range (lower density)

PV System Sizing (Behind the Meter [BTM])

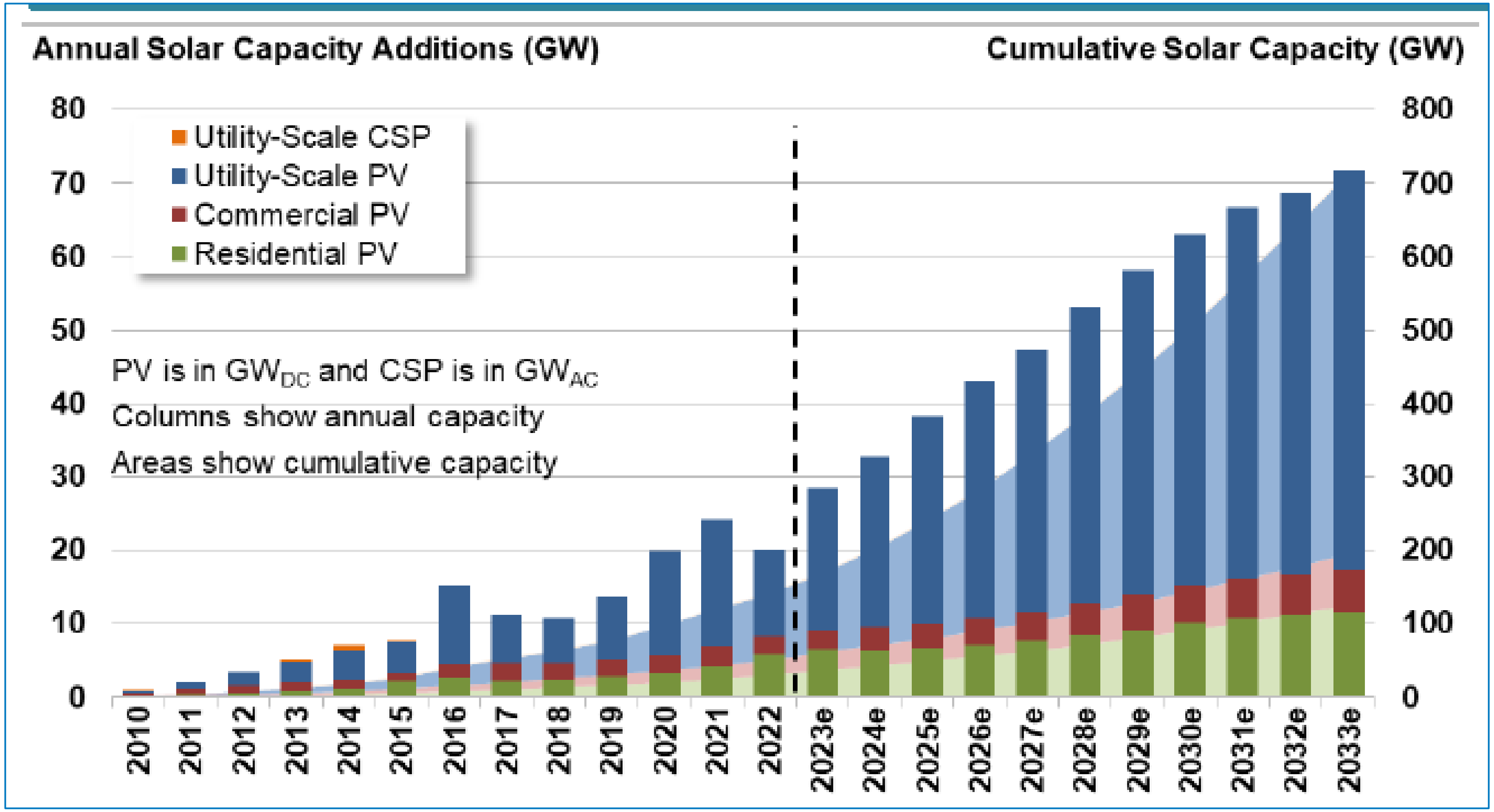
Maximum Size

- Typically, a BTM PV system should not be sized so that its annual energy production significantly exceeds the facility annual consumption (actual or anticipated).
- Typically, there is no harm in going smaller. There are many potentially good reasons to do so.

Sizing Considerations & Potential Constraints

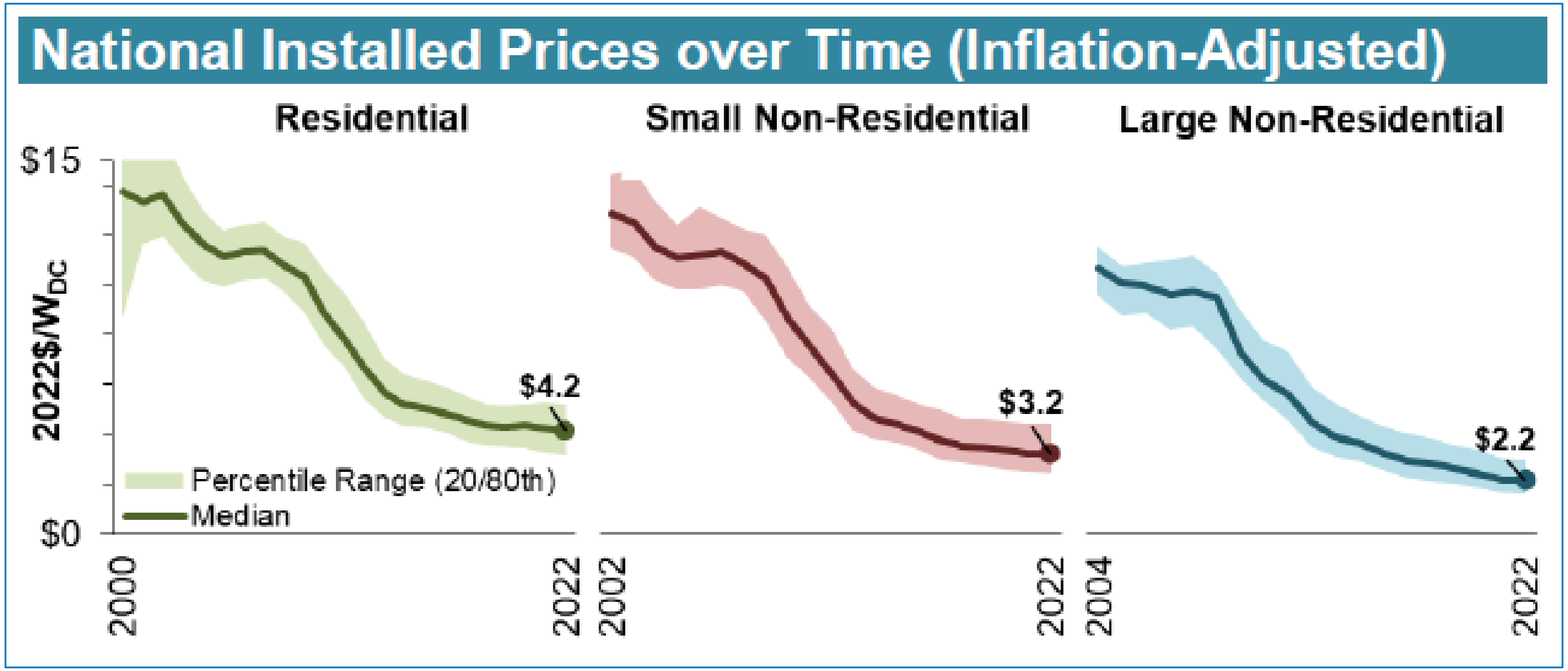
- Available funds
- Available space
- Availability (or not) of net metering
- Net metering threshold (If the net metering limit is 40-kW, think twice before installing a 41-kW system.)
- Interconnection threshold (If the least-painful interconnection process applies to systems up to 25-kW, think twice before installing a 26-kW system.)

Market – Deployment Trends (U.S.)



Source: Utility-Scale Solar, 2023 Edition, http://utilityscalesolar.lbl.gov

Market (PV) – Cost Trends (Distributed PV)



Source: *Tracking the Sun 2023 Edition*, https://emp.lbl.gov/tracking-the-sun/

- In all sectors, there is a very sharp decline in price from 2009-2014.
- Lesser rate of decline since 2014 to the present time.

Example Projects

Picuris Pueblo of New Mexico PV Array. 1.0 MW_{AC}, Fixed tilt.
Source: https://www.energy.gov/indianenergy/articles/community-solar-meet-100-energy-costs-new-mexico-tribe

Photo by Werner Slocum/NREL

Flatirons Campus PV Array. 1.0 MW_{AC}, One-axis tracking

Solar: Recap

Resource: GHI varies from 3.0 – 6.0 kWh/m^2/day over most of the continental U.S.

PV Panels/Arrays: Described in terms of watts or kW. Panel conversion efficiency typically 12% - 24%. Overall losses (from array to inverter output): ~20%

Facility Size: Utility, Distributed Generation (DG)

Space Utilization Planning Factors

- **Residential Rooftop:** ~15 watts/square foot
- **Ground mounted:** 3-4 acres per MW_{DC} (Area taken up by the array and ancillary equipment)

(PV) Market Status: Significant cost reductions in recent years have spurred explosive growth in worldwide and U.S. PV installations.

Solar: Additional Information

DOE General Solar Information (Covers a variety of topics)
https://www.energy.gov/eere/solar/how-does-solar-work

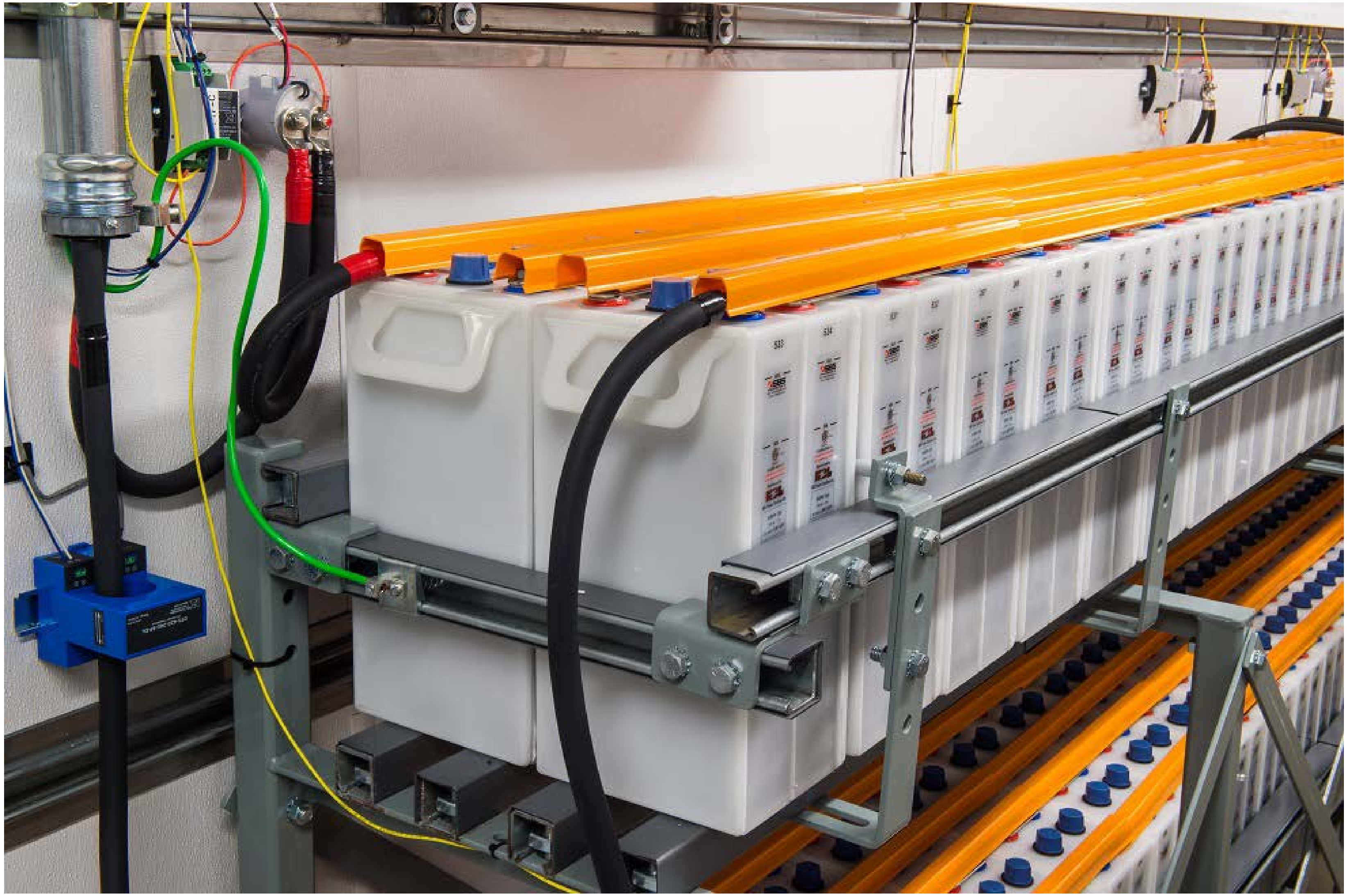
Lawrence Berkely National Laboratory (LBNL) PV Market Reports
Market reports generally provide cost, deployment, and performance trends for the technology or market segment that is the focus of the report. The reports listed below are free and updated annually.
o Tracking the Sun (Systems up to 5 MW): https://emp.lbl.gov/tracking-the-sun
o Utility-Scale Solar (Systems larger than 5 MW): https://emp.lbl.gov/utility-scale-solar/

LBNL Analysis of utility-scale PV area requirements
https://emp.lbl.gov/publications/land-requirements-utility-scale-pv

NREL PVWatts Calculator (for quick energy output estimates)
https://pvwatts.nrel.gov/

Storage 101

(Battery) Storage



(Photo by Dennis Schroeder / NREL)

Storage: Physical Characterization

Technology Characterization (Different technologies are best suited for different applications & scales)

- Energy Density [volumetric, mass]: watts-hours/liter, watt-hours/kg
- Power Density [volumetric, mass]: watts/liter, watts/kg
- Discharge time
- Scale: At what size range does this technology make sense?

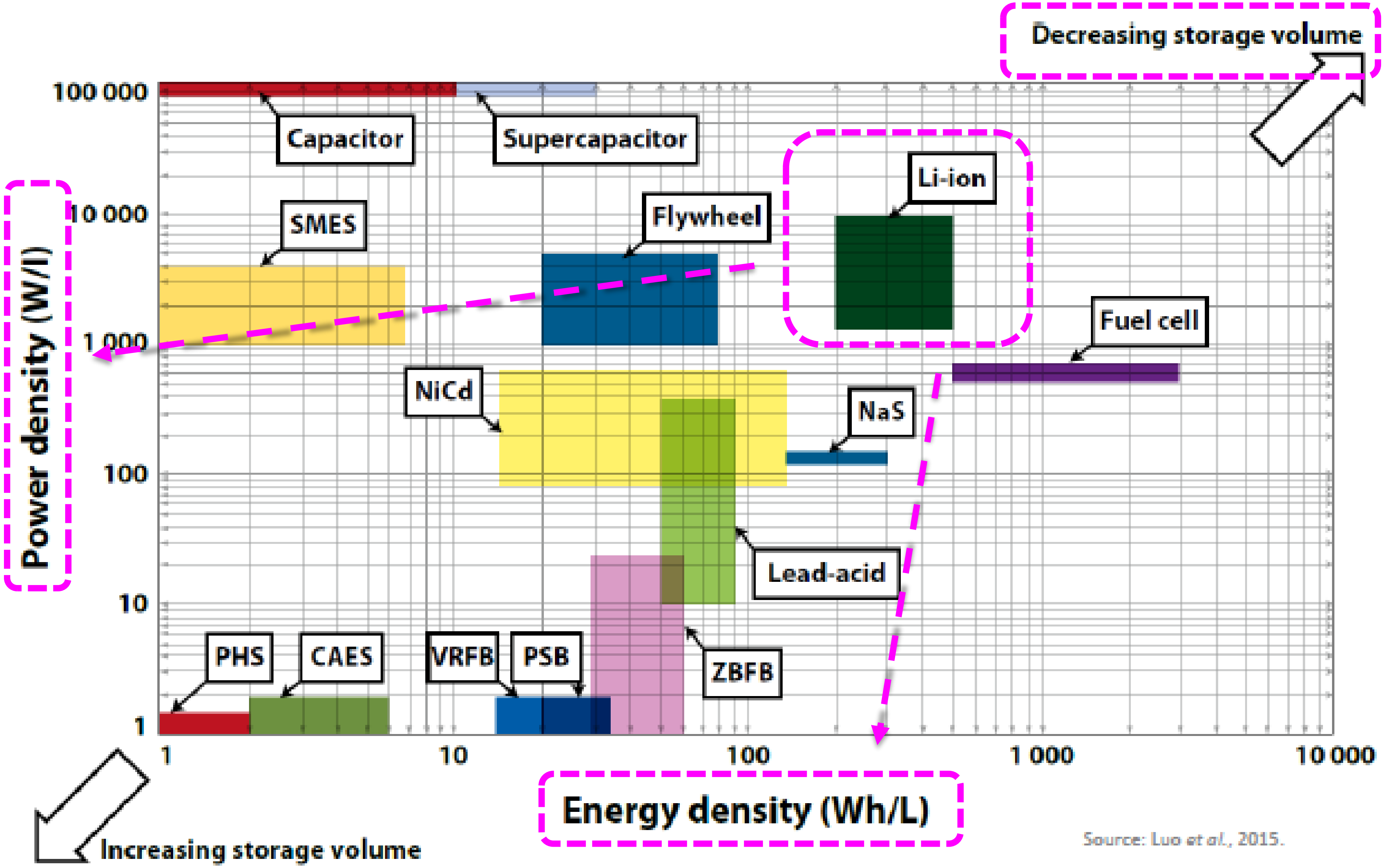
System Characterization

- Energy capacity (kWh, MWh), Similar to the fuel storage for a diesel generator
- Power capacity (kW, MW), Similar to peak output of a diesel generator—the most power that the system can provide.
  - Discharge duration = Energy capacity/power capacity:
  - For example, a 1 MW/2 MWh [1 MW/2-hr] BESS can provide 1 MW of power for 2 hours or 0.5 MW of power for 4 hours
- Overall size & mass
- State-of-charge limits
- Cycle life (Maximum cumulative energy throughput)

Potentially Desirable Controller/Inverter Features

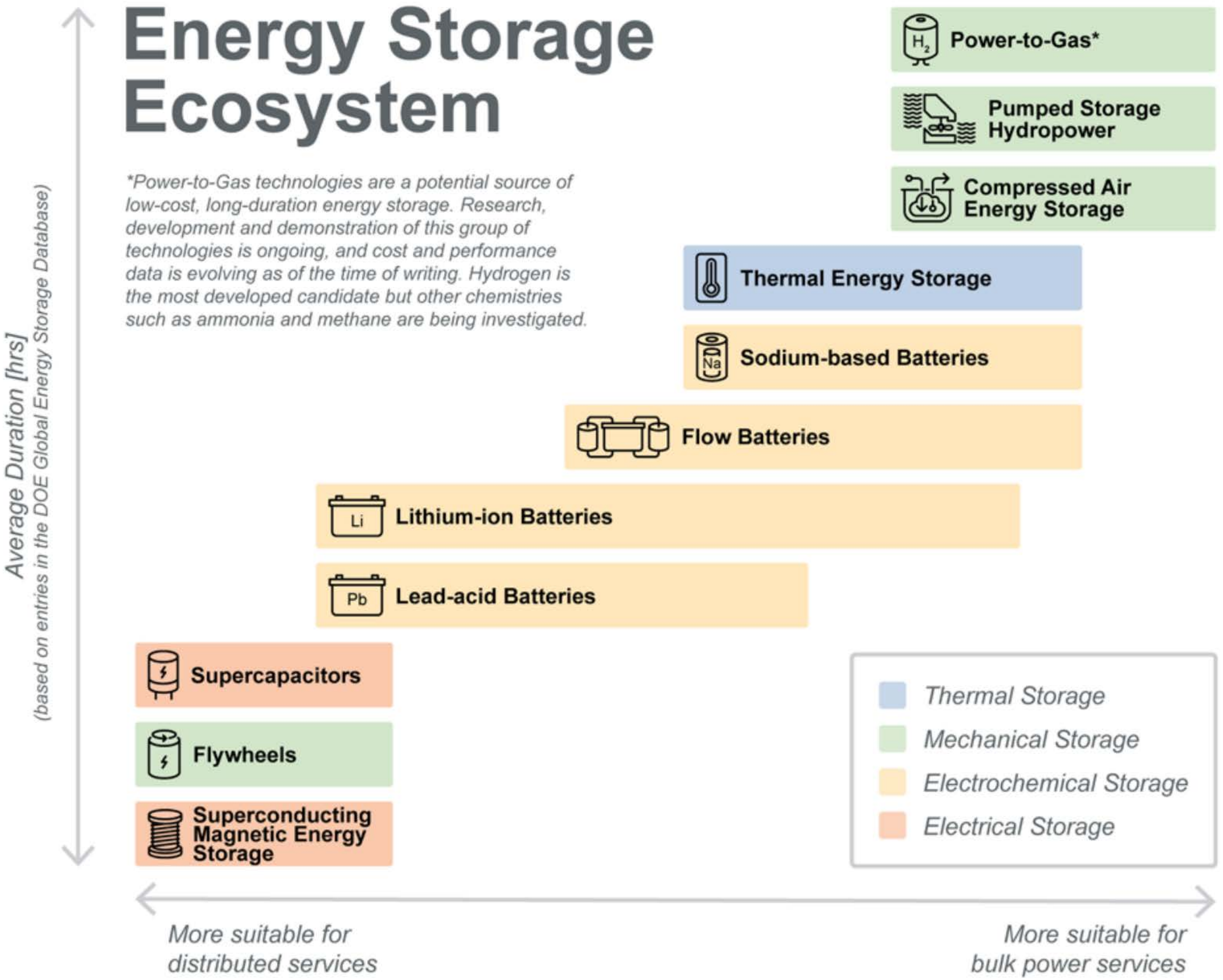
- Control: grid-following/grid-forming
- Additional functions: volt/VAR and frequency/power control
- Transition: grid-tied mode to island mode

Storage: Technologies



Source: Luo *et al.*, 2015.

Ecosystem of Energy Storage Technologies and Services



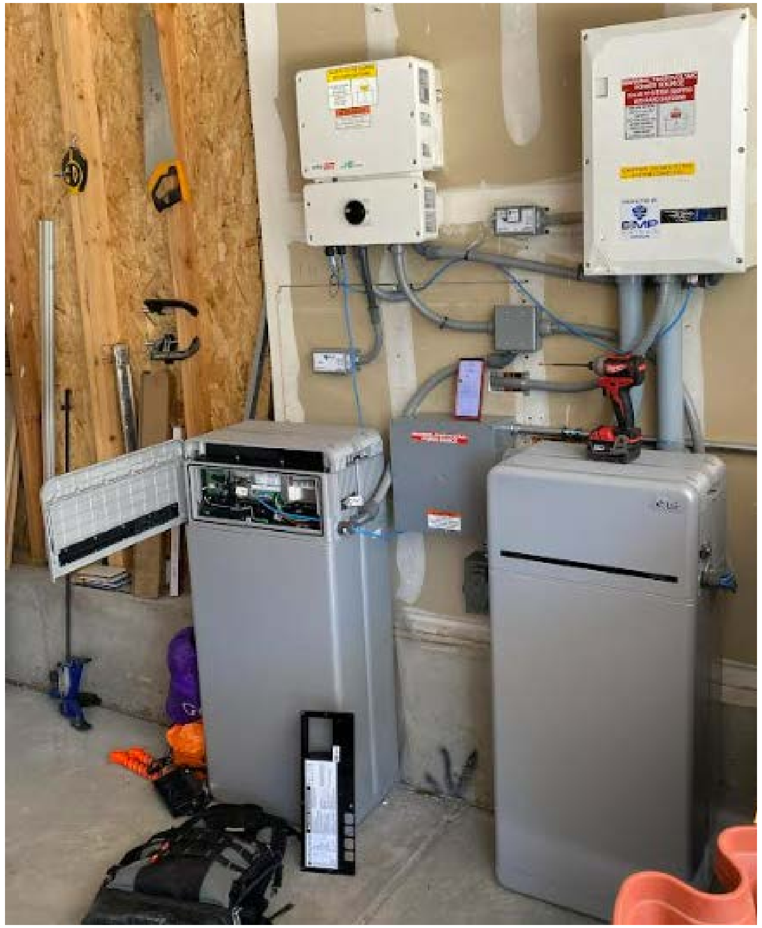
Source: Bowen, Thomas, Ilya Chernyakhovskiy, Kaifeng Xu, Sika Gadzanku, Kamyria Coney. 2021. *USAID GRID-SCALE ENERGY STORAGE TECHNOLOGIES PRIMER.* NREL/TP-6A20-76097. Golden, CO: NREL. https://www.nrel.gov/docs/fy21osti/76097.pdf.

Electrochemical Batteries

Technology	Advantages	Disadvantages
Lithium-Ion	• Relatively high energy and power density • Lower maintenance costs • Rapid-charge capability • Many chemistries offer design flexibility • Established technology with strong potential for project bankability.	• High upfront cost ($/kWh) relative to lead-acid (potentially offset by longer lifetimes) • Poor high-temperature performance • Safety considerations, which can increase costs to mitigate • Currently complex to recycle • Reliance on scarce materials.
Lead-Acid	• Low cost • Many different available sizes and designs • High recyclability.	• Limited energy density • Relatively short cycle life • Cannot be kept in a discharged state for long without permanent impact on performance • Deep-cycling can impact cycle life • Poor performance in high temperature environments • Toxicity of components.
Sodium-Sulfur	• Relatively high energy density • Relatively long cycle life • Low self-discharge.	• High operating temperature necessary • High costs.
Flow	• Long cycle life • High intrinsic safety • Capable of deep discharges.	• Relatively low energy and power density.

Lithium-ion (Li-ion) Batteries

- Newer technology than lead-acid batteries
- Popular because they are lightweight, have highly reactive elements, hold their charge, and can handle thousands of charge/discharge cycles
- Requires a ‘Battery Management System,’—battery package often includes the inverter & protection systems
- Most common types of Li-ion batteries:
  - Lithium iron phosphate (LFP)
  - Lithium nickel manganese cobalt oxide (NMC)
  - Lithium nickel cobalt aluminum oxide (NCA)
  - Lithium manganese oxide (LMO)
  - Lithium titanate (LTO)

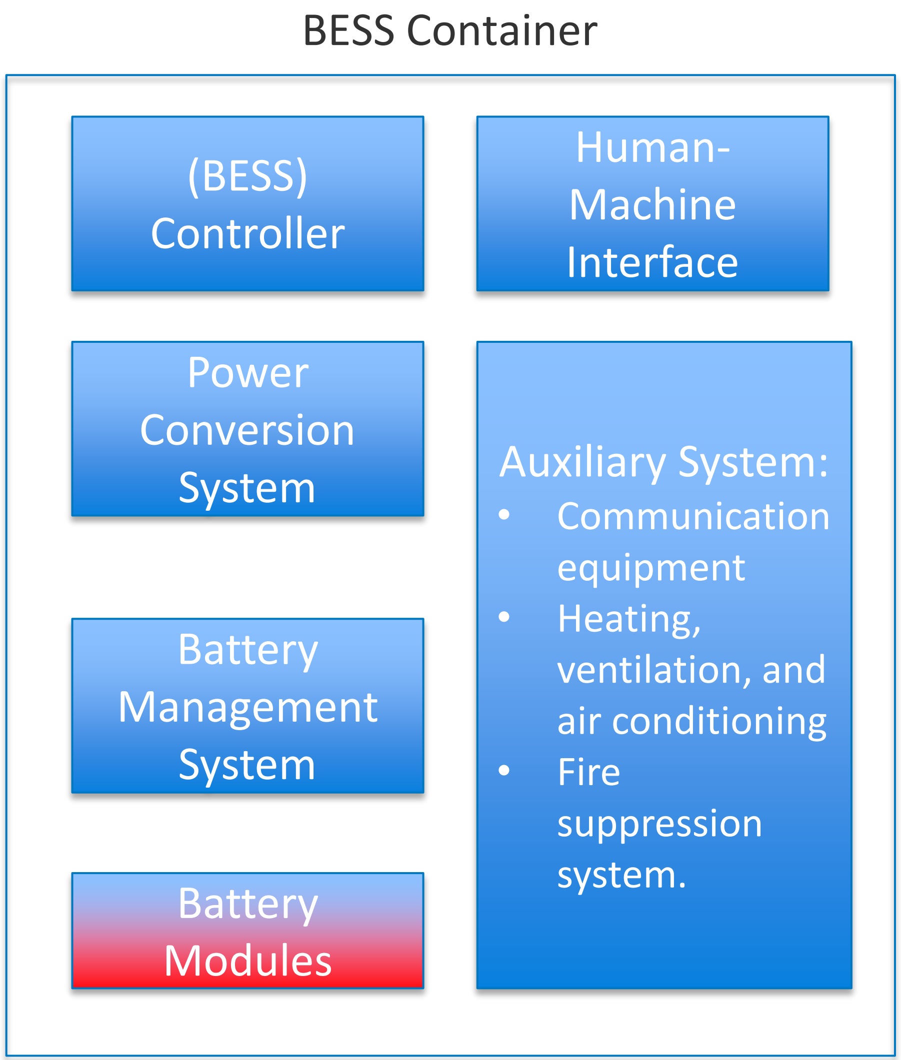


Two 16 kWh Battery Units

Photo by Andy Walker/NREL

Equipment Needed To Manage BESS

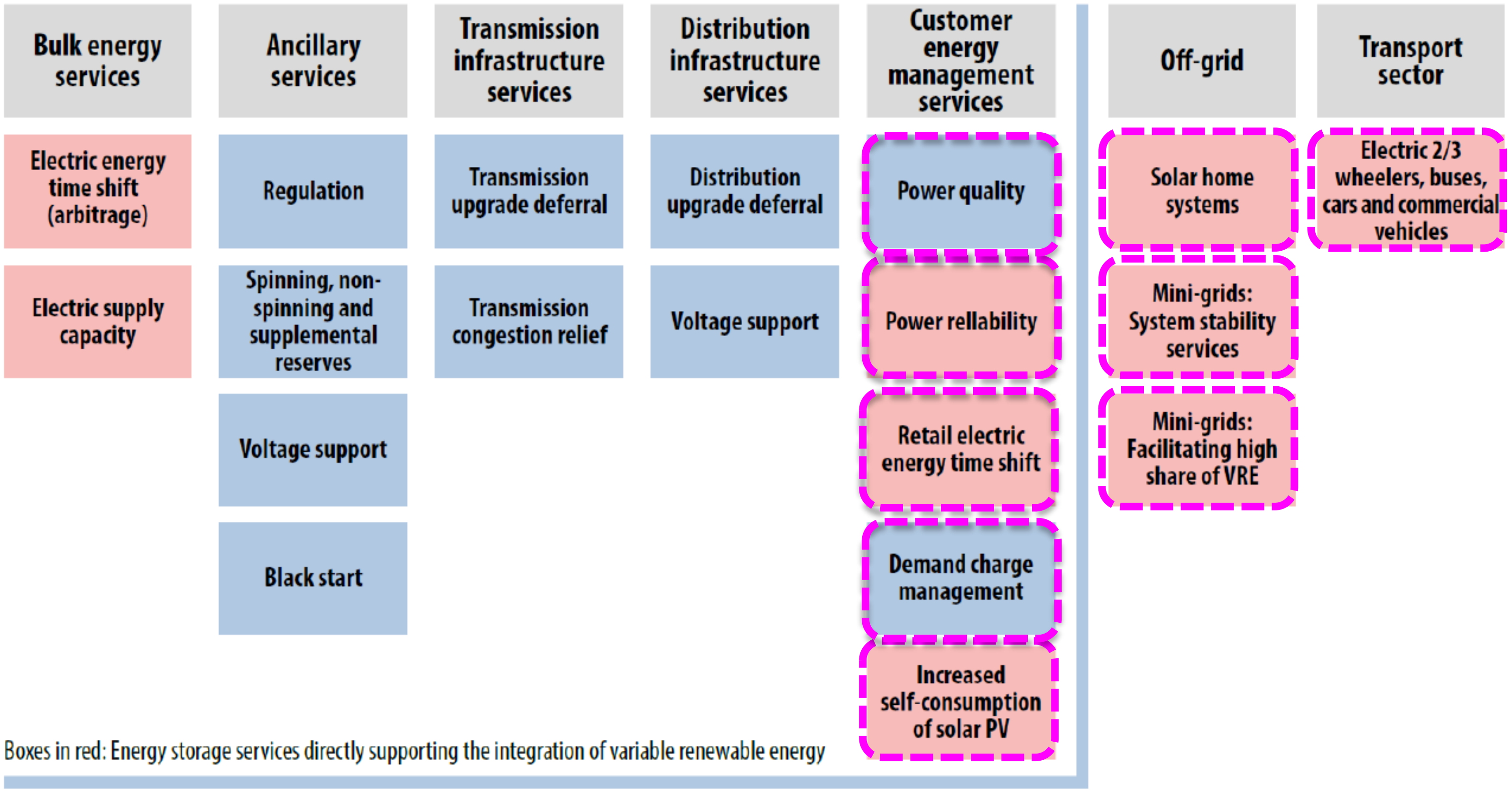
- **Battery management system:** responsible for reliable operation of batteries, monitors and controls batteries, communicates with power conversion system.
- **Power conversion system:** responsible for converting AC to DC while charging and DC to AC while discharging, grid-following or grid-forming mode, synchronization.
- **Controller:** communicates with battery management system and power conversion system. Responsible for safe operation of BESS following received command from microgrid controller.



Storage: Services & Value Streams

Battery energy systems can serve a variety of needs for different customers.

The dashed lines show the services typically provided by behind the meter (BTM) storage systems.



Modified from Source: IRENA report" ELECTRICITY STORAGE AND RENEWABLES: COSTS AND MARKETS TO 2030", October 2017

BTM Battery Storage: Potential Rationales

Ends (Why)	Means (How)	Comments
Resilience	Use battery as an uninterruptible power supply (UPS)	o Most applicable for facilities that experience numerous/prolonged power outages. o Battery required for PV to operate during power outages.
Save Money	Store Excess PV for later use.	o Beneficial when PV produces significant excess PV and net metering is not available.
Save Money	Load shifting (Charge the battery during low-cost periods for later use during high-cost periods)	o Applicable to facilities served under a time of use rate.
Make Money	Load shifting [Arbitrage] (Charge the battery during low-cost periods and sell the energy during high-cost periods)	o Applicable to facilities served under a time of use rate.
Save Money	Peak shaving (Reduce peak demand)	o Applicable to facilities served under a tariff with a demand charge component.
Save Money System Benefit	Demand response	o Requires the availability of a demand response program for which the system is eligible.

A project may be built for multiple motivations. For example, a project may be installed for resilience purposes and then used for load and peak shaving.

Storage: Sizing a System

Notes on Battery Lifetime.
- Float Life: Maximum lifespan regardless of how little the battery is used.
- Energy throughput: Maximum cumulative energy that can be cycled through the battery (This information is typically not easy to find).
  - Typically, with PV the batteries aren't cycled more than once per day

Power: Does the discharge rate (kW) meet the desired power requirement?

Energy:
- For behind the meter systems, a useful metric is the length of time the battery can meet the average load, "hours of autonomy".
- Example: A battery with 10 kWh of storage capacity attached to a facility with an average load of 2 kW, would provide 5 hours of autonomy.

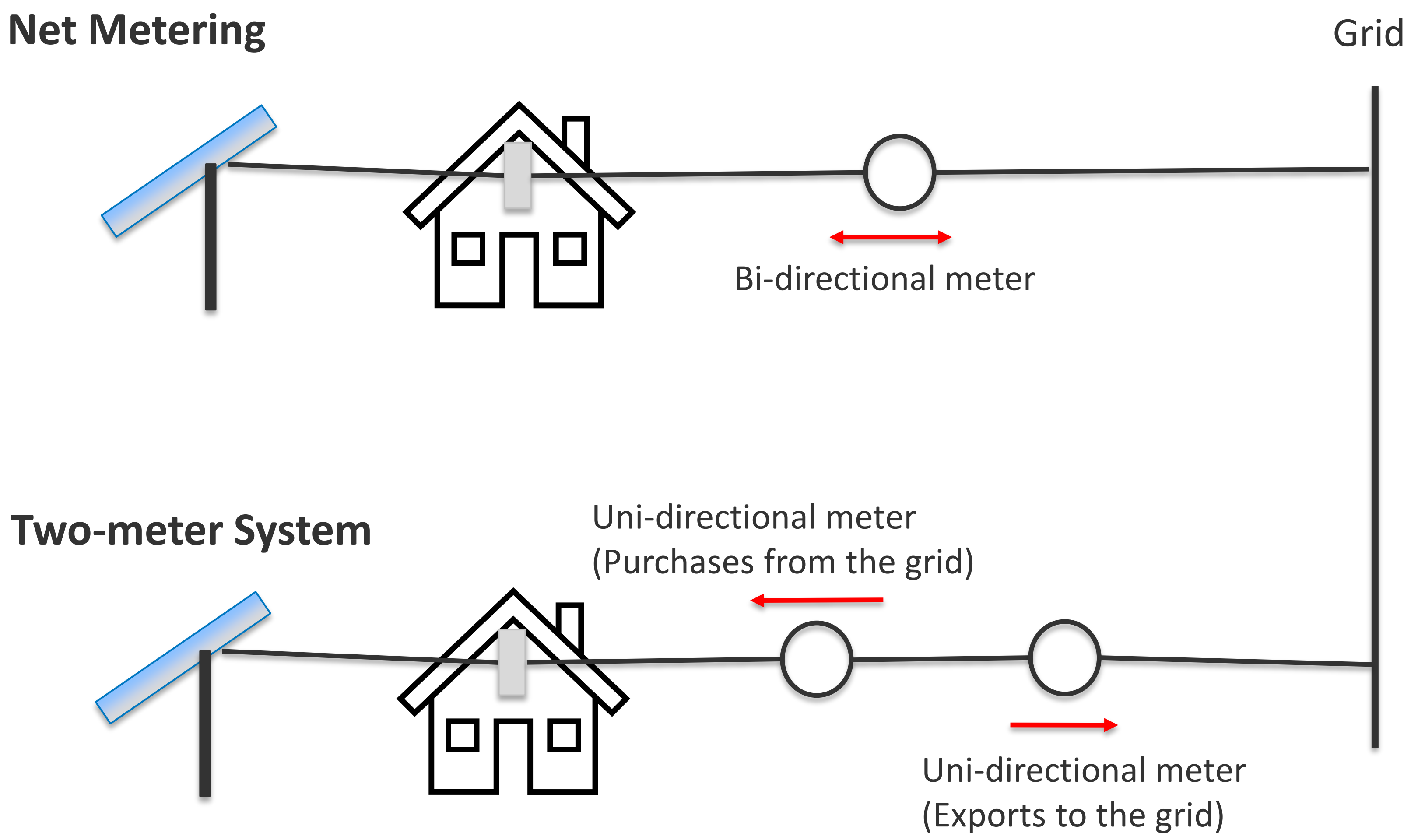
Rules of Thumb
- Storage generally has decreasing marginal utility as the storage size increases.
  - Storage typically best used for frequent, short outages
  - Longer outages are typically more economically served with a generator
- Residential (off-grid): up to several days
- Residential (grid connected): up to 1-2 days
- Large commercial: up to a few hours

Net Metering

Net Metering: What is it?

Net metering is a compensation arrangement where the compensation for electricity exported to the grid is the same as the rate paid for electricity purchased from the grid. Purchases from the grid are tracked on a net basis (i.e., the meter spins backwards when electricity is exported to the grid).

Under a two-meter system exports to the grid and purchases from the grid are tracked separately. The compensation for electricity exported to the grid is different (less) than the rate for purchases from the grid.



Net Metering Example (1 of 2)

Situation
Your house uses 1,000 kWh per month. You pay $0.12 per kWh.   You install a PV system that generates 900 kWh per month.

What is your savings under:

- Net metering?
- Two-meter system?
    - Assumption: 500 kWh of PV generated energy is used on site and 400 kWh is exported to the grid
    - Assumption: The buyback rate for energy exported to the grid is $0.05/kWh

Net Metering Example (2 of 2)

	No PV	Net Metering	Two Meter
Total Consumption (kWh)	1,000	1,000	1,000
Total PV energy production (kWh)		900	900
PV energy used on site (kWh)		500	500
PV energy exported to grid (kWh)		400	400
Energy imported from grid (kWh)	1,000	500	500
Net energy imported from grid (kWh)	1,000	100	100
Electricity Bill ($)	$120.00	$12.00	$40.00
Savings ($)	$0.00	$108.00	$80.00

<u>Notes on how bills are calculated</u>

- No PV: 1,000 kWh x $0.12/kWh = $120
- Net Metering: 100 kWh x $0.12/kWh = $12
- Two Meter: 500 kWh x $0.12 – 400 kWh x $0.05 = $40

Net Metering: Factoids & Considerations

Specific net metering programs vary in their details

- "True-up" period (monthly or annual)
- Treatment of net-excess generation
- Max system capacity eligible for net metering
- Multiple meter aggregation (allowed or not, and if so, under what circumstances)

Considerations

- Net metering (or lack thereof) is less of an issue in situations where all or most of the RE energy serves the load. This is often the case when the annual RE energy production is small compared the consumption of the facility being served. (In this case all/most of the energy production is used on-site)
- Typically, avoid a system capacity that just exceeds the net metering limit (in areas where net metering is allowed).
- Typically, avoid sizing the renewable energy system so that it's annual production significantly exceeds the annual consumption of the facility it serves.

Solar + Storage Project Financing

Investment Tax Credit (ITC) and Production Tax Credit (PTC)

- For taxable business entities (federal agencies are not eligible):
  - Certain tax-exempt entities are eligible for direct payment of tax credits
- Certain projects are eligible for either the ITC or PTC, not both
- Projects can qualify for additional credit amounts, described below:

Category	Amount* for Projects <1MW AC (Cumulative)	Amount* for Projects >1MW AC (Cumulative)
Base Tax Credit	ITC: 30% | PTC: 2.75¢/kWh	ITC: 6% | PTC: 0.5¢/kWh
Wage and Apprenticeship Requirements	N/A	ITC: +24% | PTC: +2.25¢/kWh
Domestic Content Minimums	ITC: +10% | PTC: +0.3¢/kWh	ITC: +10% | PTC: +0.3¢/kWh
Siting in Energy Community	ITC: +10% | PTC: +0.3¢/kWh	ITC: +10% | PTC: +0.3¢/kWh
Siting in Low-Income Community or on Indian Land (<5 MW AC)	ITC: +10% | PTC: N/A	ITC: +10% | PTC: N/A
Qualified Low-Income Residential Building Project or Economic Benefit Project	ITC: +20% | PTC: N/A	ITC: +20% | PTC: N/A

*The ITC amount is a percentage of the total qualifying project cost basis. All values assume labor requirements are met.

Additional Technologies Eligible for ITC

Energy storage technologies (including thermal storage)

- Expansions of storage capacity are eligible for the ITC as well, as long as the storage capacity is increased by at least 5 kWh

Microgrid controllers

- Must be for a system between 4 kW to 20 MW
- Must be capable of operating both in connection with the electrical grid and independently from the grid
- Eligibility may change in 2025

Interconnection costs

- Must be associated with qualified ITC technology with capacity less than 5 MW AC

Solar + Storage Applications for REAP

Application Review: Observations

- Applications can be categorized by total project cost (TPC):
  - Below $200k, >$200k <$1M, >$1M
- Primary use case of the system:
  - Utility bill saving
  - Net metering
  - Exporting to the grid
  - Resilience (During outage powering the farm)
  - Off-grid system reducing the reliance on diesel generator

Application Review: Observations

- Applications Contains:
  - Cover most of the information
  - Size of the PV and storage system
  - Datasheets and warranty details
  - Project plan and cost information
  - Potential grants and benefits and simple payback calculations
  - Other details: Site lease, permits and project contract

- Missing details:
  - Justification of the sizes of the PV and BESS:
    - how system will be operated/controlled (during outage)
    - Cost savings from BESS
  - Communication with utility about interconnection/net metering/export
  - Any other auxiliary system requirements
  - Previous project details of similar nature

Application Review: Process

- Process:
  - Categorize the application based on TPC
  - Administrative checks:
    - Cover all the information
    - Lease contract
    - Project contract
  - Technical checks:
    - System sizes and justifications
    - System specifications
    - Techno-economic considerations
    - Warranty information
    - Permits and interconnection
  - Project management checks:
    - Company qualifications
    - Project team qualifications
    - Project timeline and procurement
    - Operations and Maintenance

Application Recommendations

For any proposals above TPC of 200k

- Providing justifications for the size of the PV and BESS,
  - Size of the PV, can not export to the grid more than ~10-20% of PV generation
  - BESS: identify potential use of BESS and justify,
    - Off grid system (not grid connected)
    - For excess PV generation storage to maximize the use of PV generation
    - Use during the outage (justify with historical outage data from the utility + justify sizing for operating the system to survive at least X number of hours)
- Need to highlight how the system will be operated, identify if any control system required to control the system and provide the catalog/brochure of the controller
- Can perform REopt analysis: https://reopt.nrel.gov/tool
- Providing previous project experience of similar projects
  - Details of the project site, and site point of contact
- Proof of communication with utility about interconnection, net metering and allowable export to the grid