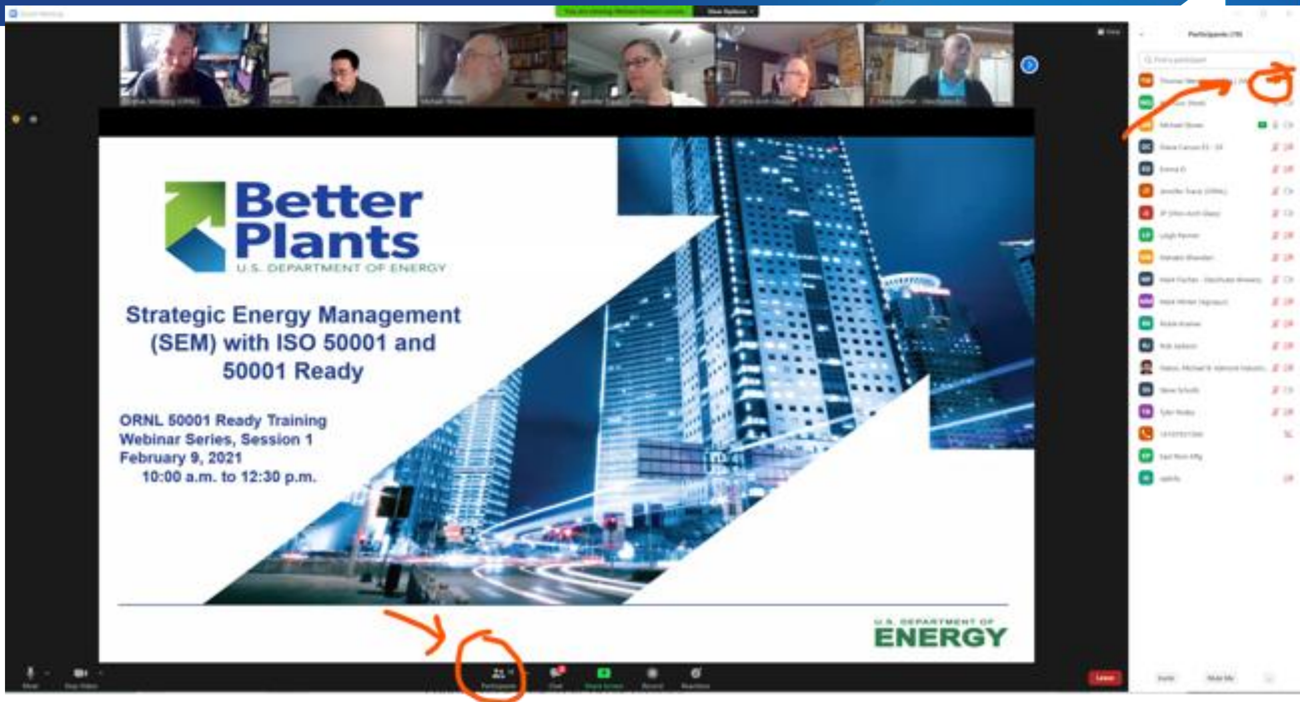
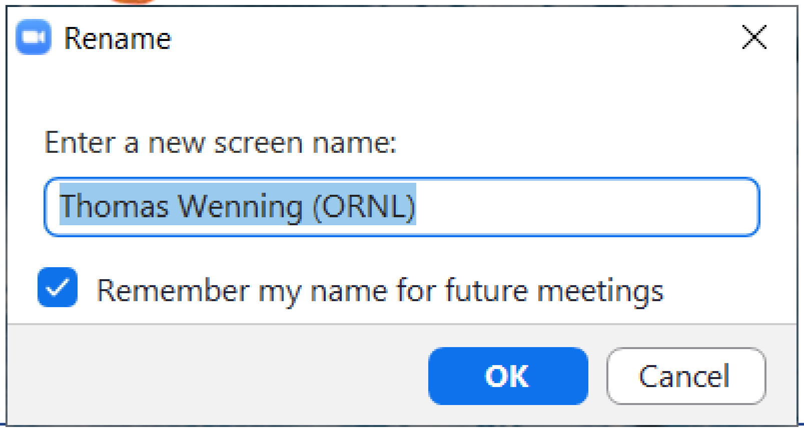
Rename Yourself to be your Real Name (Company Name)

1. Click on Participant list
2. Go to the right and hover over your name
3. Select “More” & “Rename”
4. Enter your company name in brackets
5. Turn on your camera ☺





General Information

- Schedule: Every Tuesday (June 3rd – July 8th) morning @ 10am ET
- Sessions will be recorded
- We want these VT to be interactive!
- We're hoping you finish the VT with some big progress
- There will be homework – just try your best!
    - "You'll get out what you put in!"

Links:
https://bptraining.ornl.gov/
http://betterbuildingssolutioncenter.energy.gov/better-plants
https://measur.ornl.gov

Better Plants®
U.S. DEPARTMENT OF ENERGY

Virtual Training: Onsite Energy Generation and Storage

Exploring Onsite Energy For Your Facility

Session #2
June 10, 2025
10:00am – 12:00pm EST

U.S. DEPARTMENT OF ENERGY

Training Overview

1. 06/03: Introduction to Onsite Energy Generation
2. 06/10: Exploring Onsite Energy For Your Facility
3. 06/17: Evaluating an Onsite Energy System
4. 06/24: Onsite Energy Success Stories and Overview Of Geothermal Systems
5. 07/01: Overview of Combined Heat and Power, Onsite Biomass, and Small Modular Reactors
6. 07/08: Considerations for Onsite Energy and Renewable Energy Supply Options

Agenda

1 ▪ Homework Discussion and Recap

2 ▪ Introduction to Onsite Energy Technologies: Solar, Wind Power, and Battery Storage
  ▪ *Indraneel Bhandari, ORNL*

3 ▪ PVWatts Demonstration

4 ▪ Q&A

5 ▪ Homework Assignment

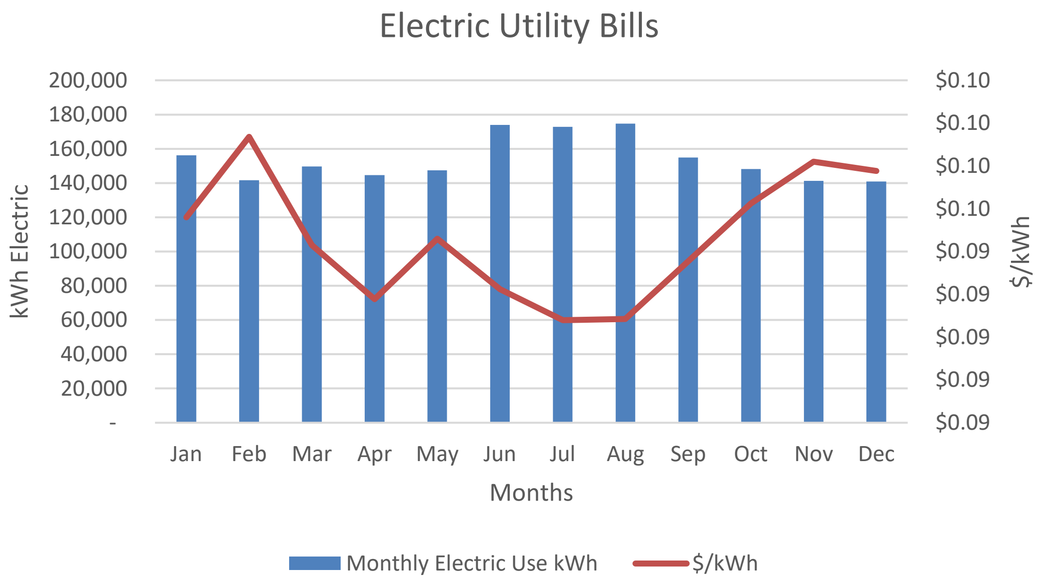
6

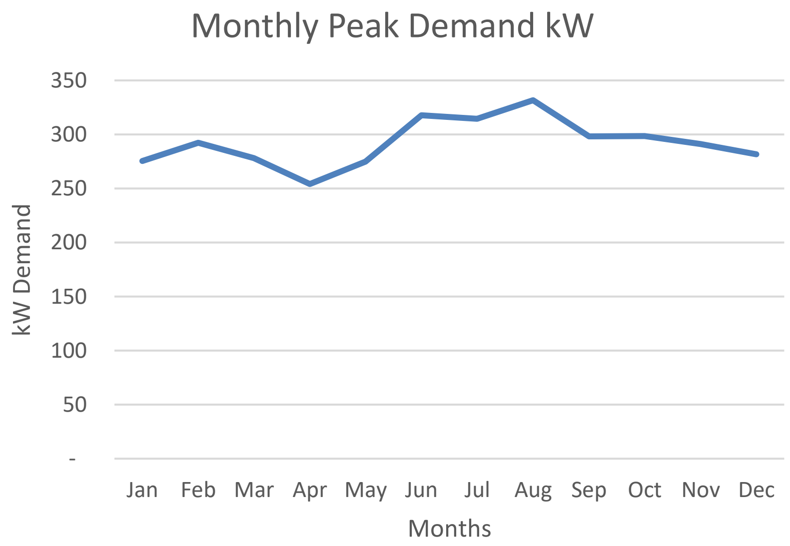
Review of Session #2 Homework

- Complete the utility bill information and find your facility roof or ground space for PV solar.
  - Retrieve facility address and usable roof/ground space
  - Collect Electric bills for your facility
    - Complete the utility bill exercise (Excel)

Review of Session #2 Homework

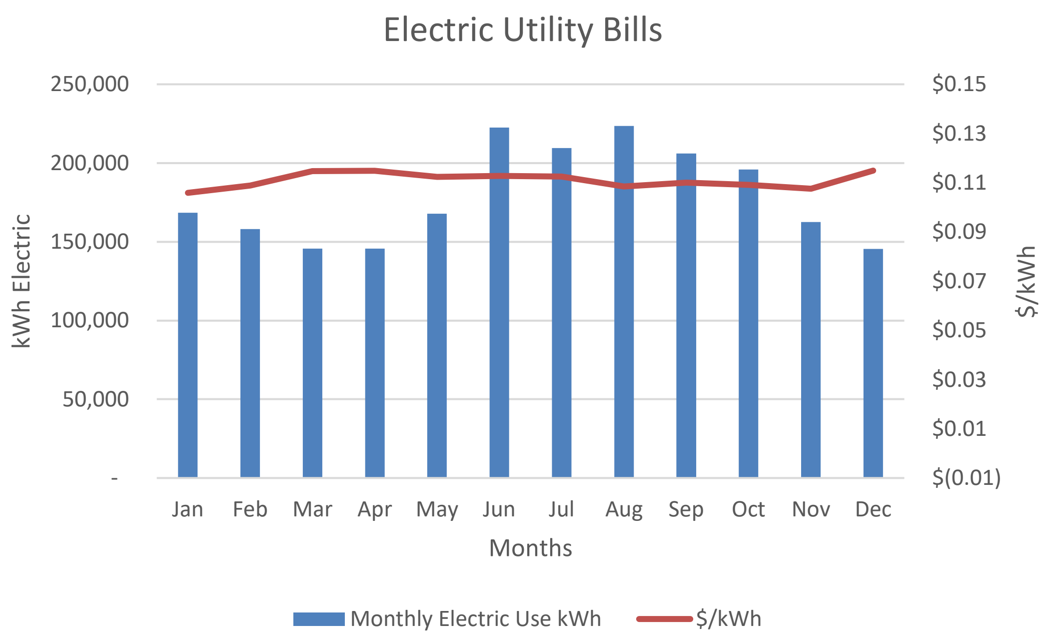
- 2360 Cherahala Blvd, Knoxville, TN 37932
  - 1,845,968 kWh
  - 15,000 SF roof space

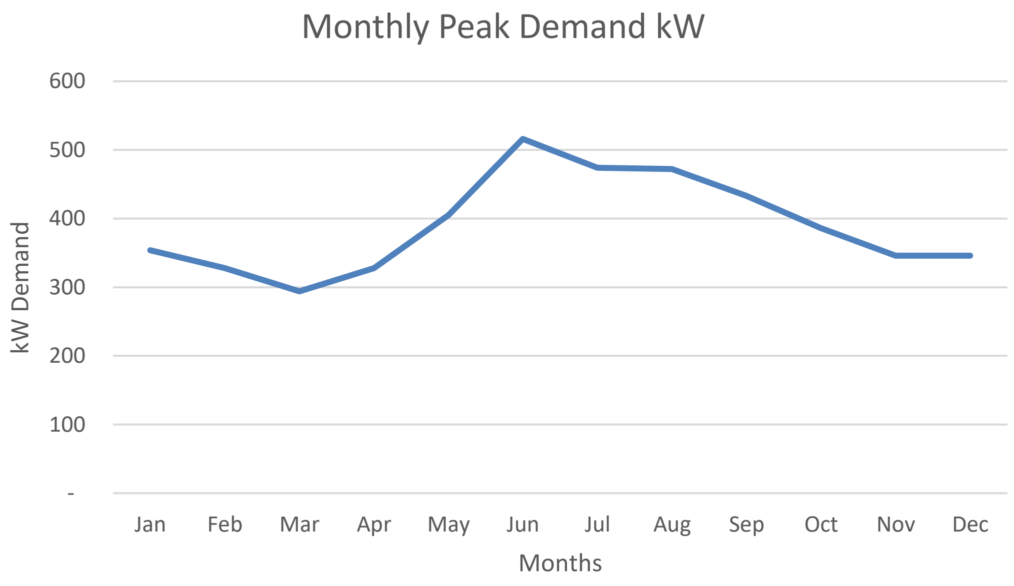




Review of Session #2 Homework

- Automotive Facility in Michigan
  - 2,151,156 kWh per annum
  - Average Demand 390 kW and Peak Monthly Demand 516 kW



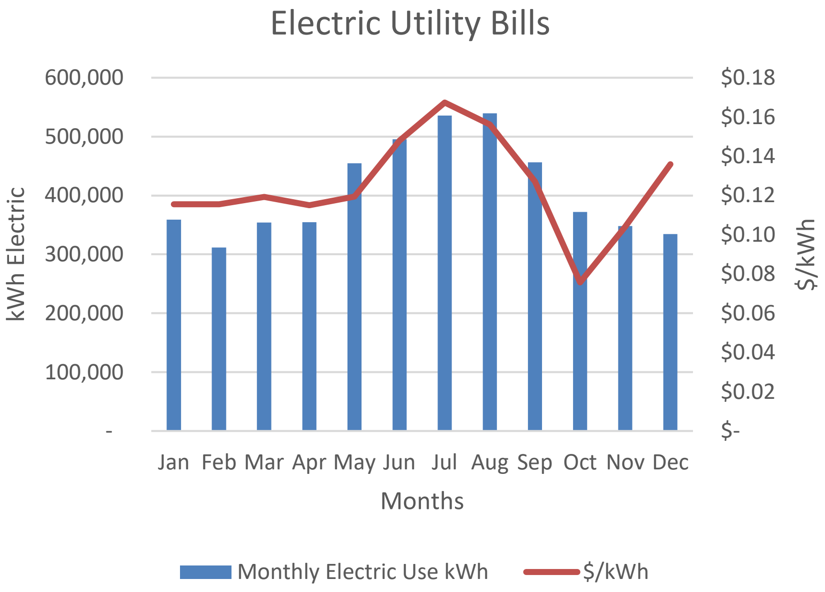


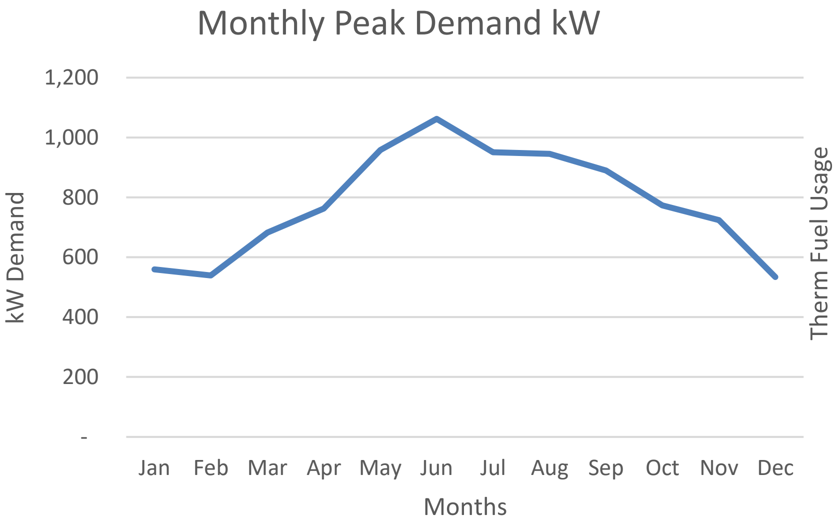
Review of Session #2 Homework

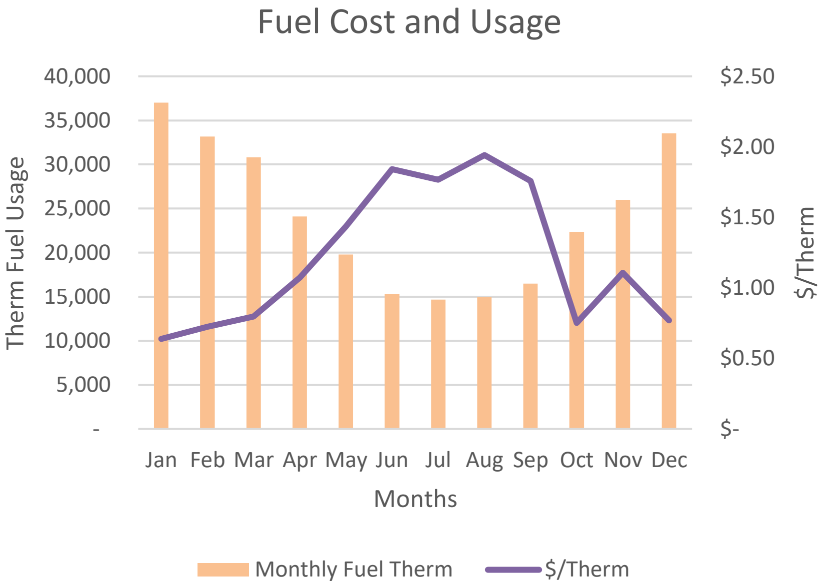
- Automotive Facility in Michigan
  - 2,151,156 kWh
  - 47,916 SF of vacant land available
  - 230,000 SF landscape and parking lot
  - Roof determined to be unsuitable to support solar panels

Review of Session #2 Homework

- Submission #2
  - 4,915,365 kWh per annum
  - Average Demand 782 kW and Peak Monthly Demand 1,062 kW

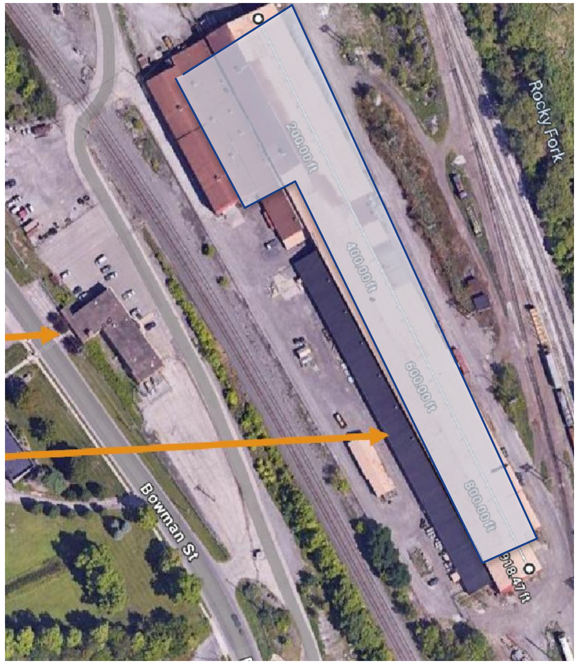






Review of Session #2 Homework

- Submission #3: Iron & Steel Plant in Ohio
  - 33M KWh if operating 30 days with no Maintenance Outages
  - 26M to 28M KWh during some months that include 3-4 days down for maintenance
  - 1,132,560 SF (26 acres) of vacant land available
  - 90,000 SF roof
  - Roof determination and site constraints

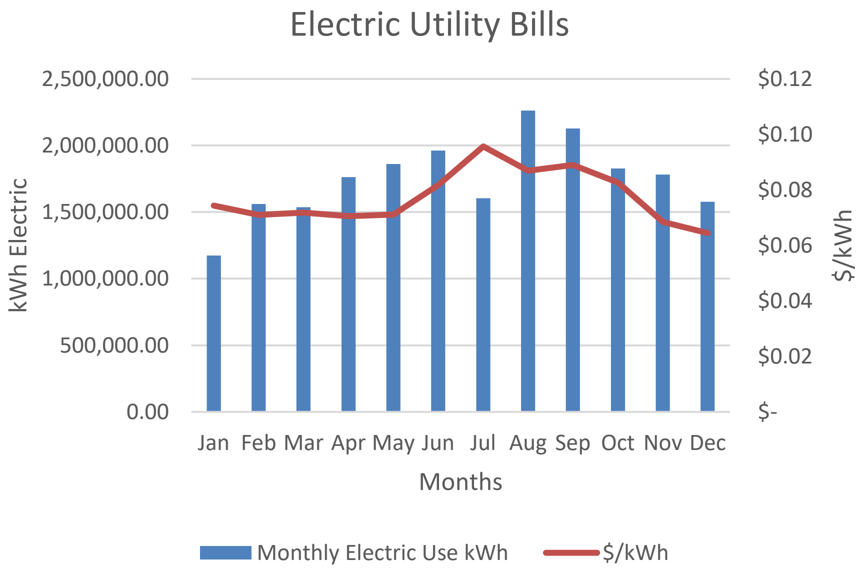


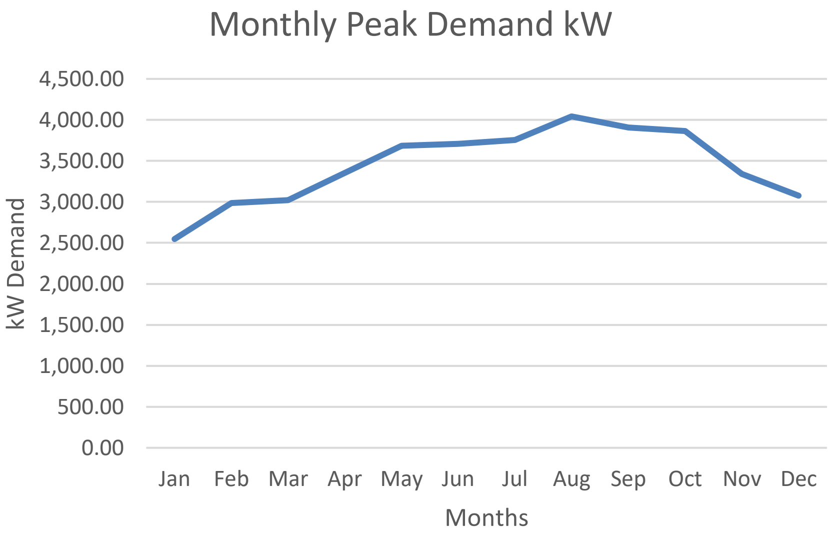
138kv utility feed

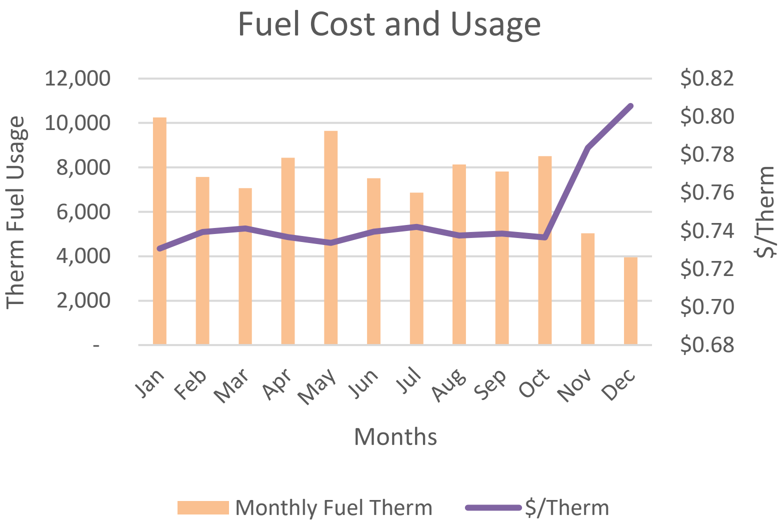
2400 volt 3-phase Delta circuit feed

Review of Session #2 Homework

- Submission #4: Automotive Parts Facility
  - 21,035,458 kWh per annum
  - Average Demand 3,440 kW and Peak Monthly Demand 4,042 kW







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U.S. DEPARTMENT OF ENERGY

Exploring Onsite Energy For Your Facility

Indraneel Bhandari
Oak Ridge National Laboratory

Acknowledgements

- U.S. Department of Energy, Industrial Technologies Office (ITO)
- Christine Holland, PNNL, Economist
- Andy Walker, NREL, Senior Research Fellow
- Jennifer King, NREL, Senior Researcher
- Paul Lemar, ORNL

Roadmap for Implementing Onsite Energy Projects

Adapted from US Environmental Protection Agency, 2018, Guide to Purchasing Green Power: Renewable Electricity, Renewable Energy Certificates, and On-site Renewable Generation. https://www.epa.gov/sites/production/files/201601/documents/purchasing_guide_for_web.pdf

Benefits of Onsite Energy

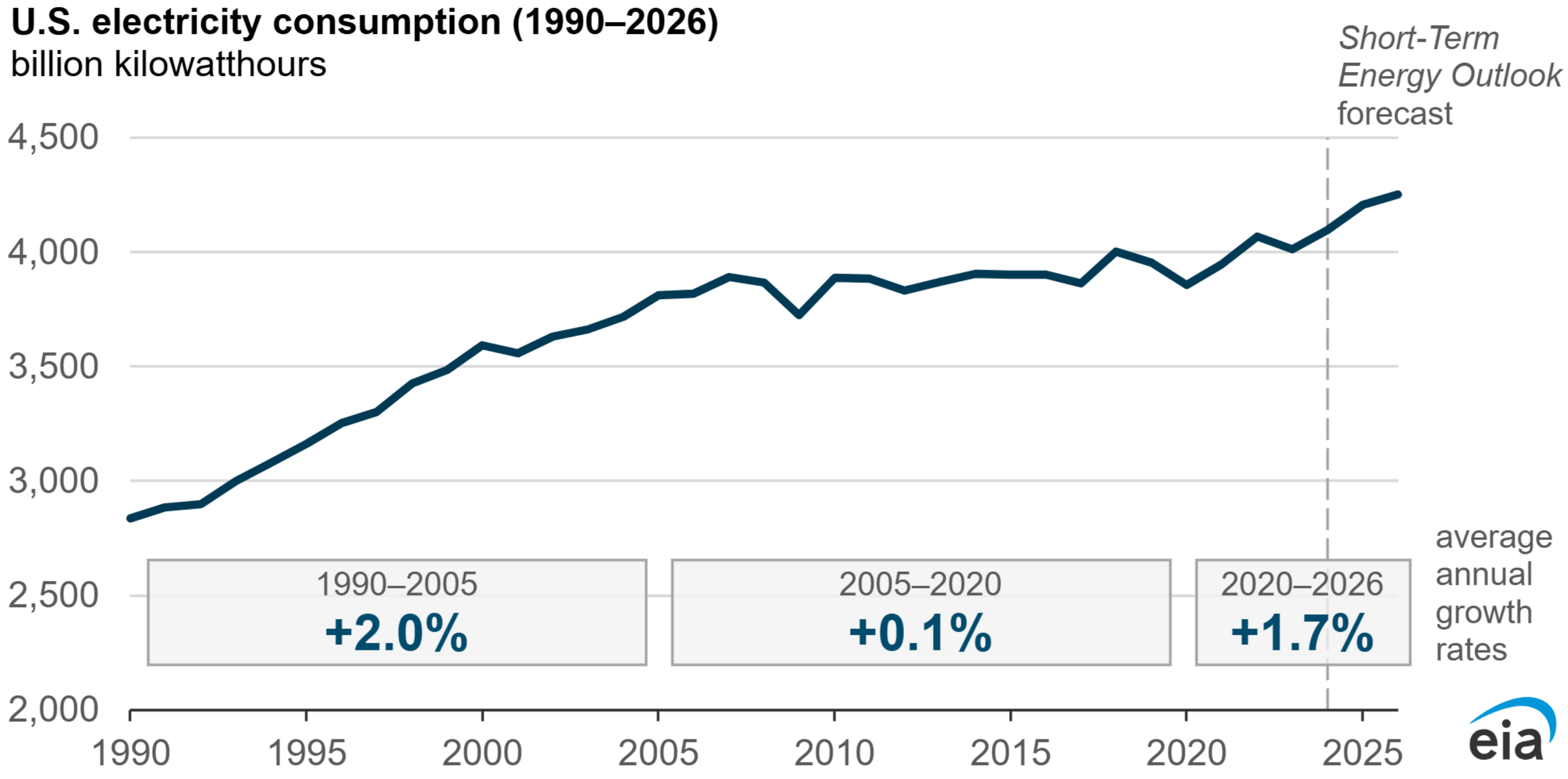
Roadmap for Implementing Onsite Energy Projects

Adapted from US Environmental Protection Agency, 2018, Guide to Purchasing Green Power: Renewable Electricity, Renewable Energy Certificates, and On-site Renewable Generation. https://www.epa.gov/sites/production/files/201601/documents/purchasing_guide_for_web.pdf

Poll Time!

U.S. Electricity Demand Rise

- Commercial Sector
- Information Technology
- Fleets and Transportation
- Residential Sector
- Manufacturing Sector

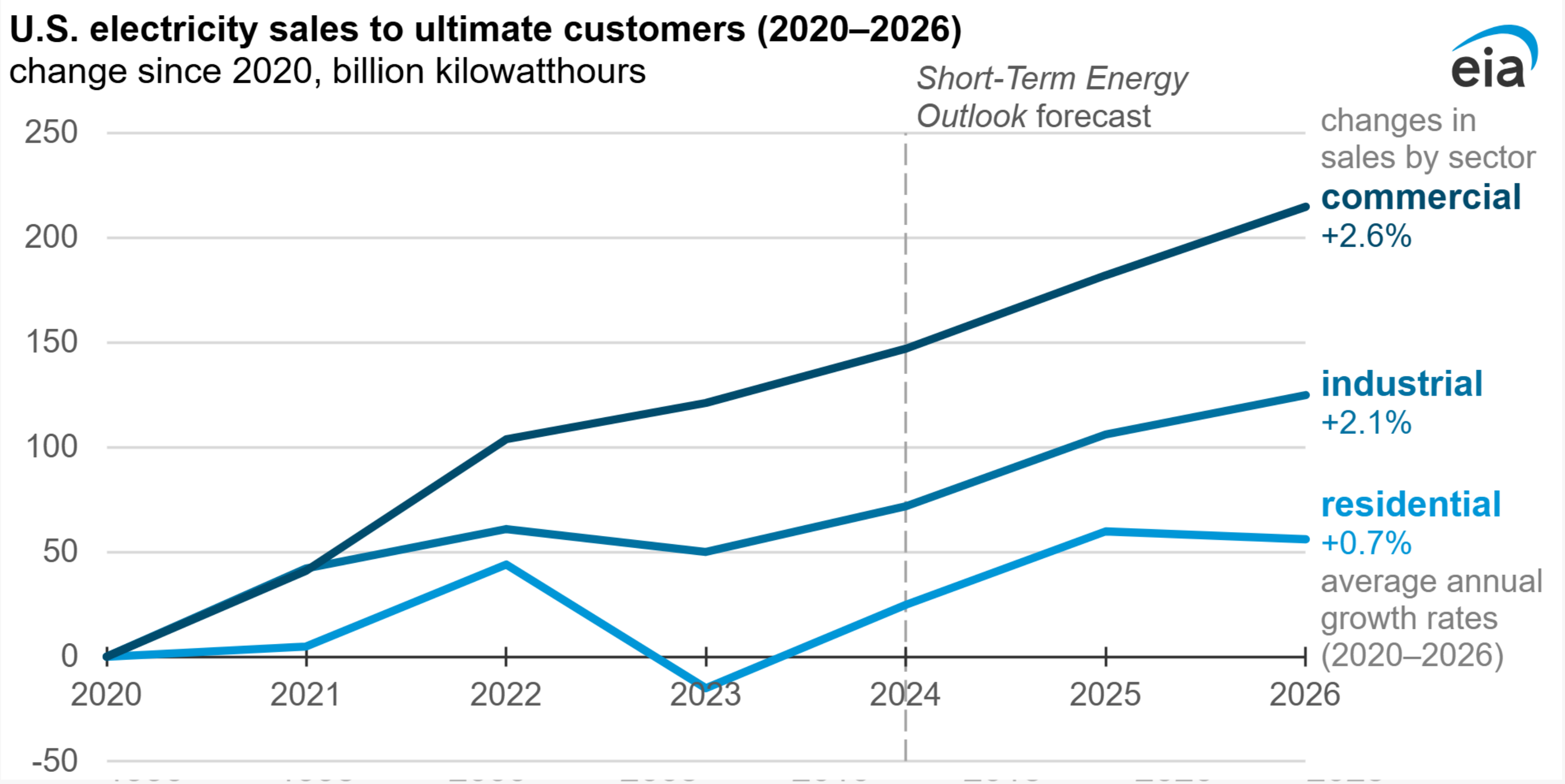


Demand is **Rising**

Source: U.S. Energy Information Administration, *Monthly Energy Review* and *Short-Term Energy Outlook*, May 2025

U.S. Electricity Demand Rise

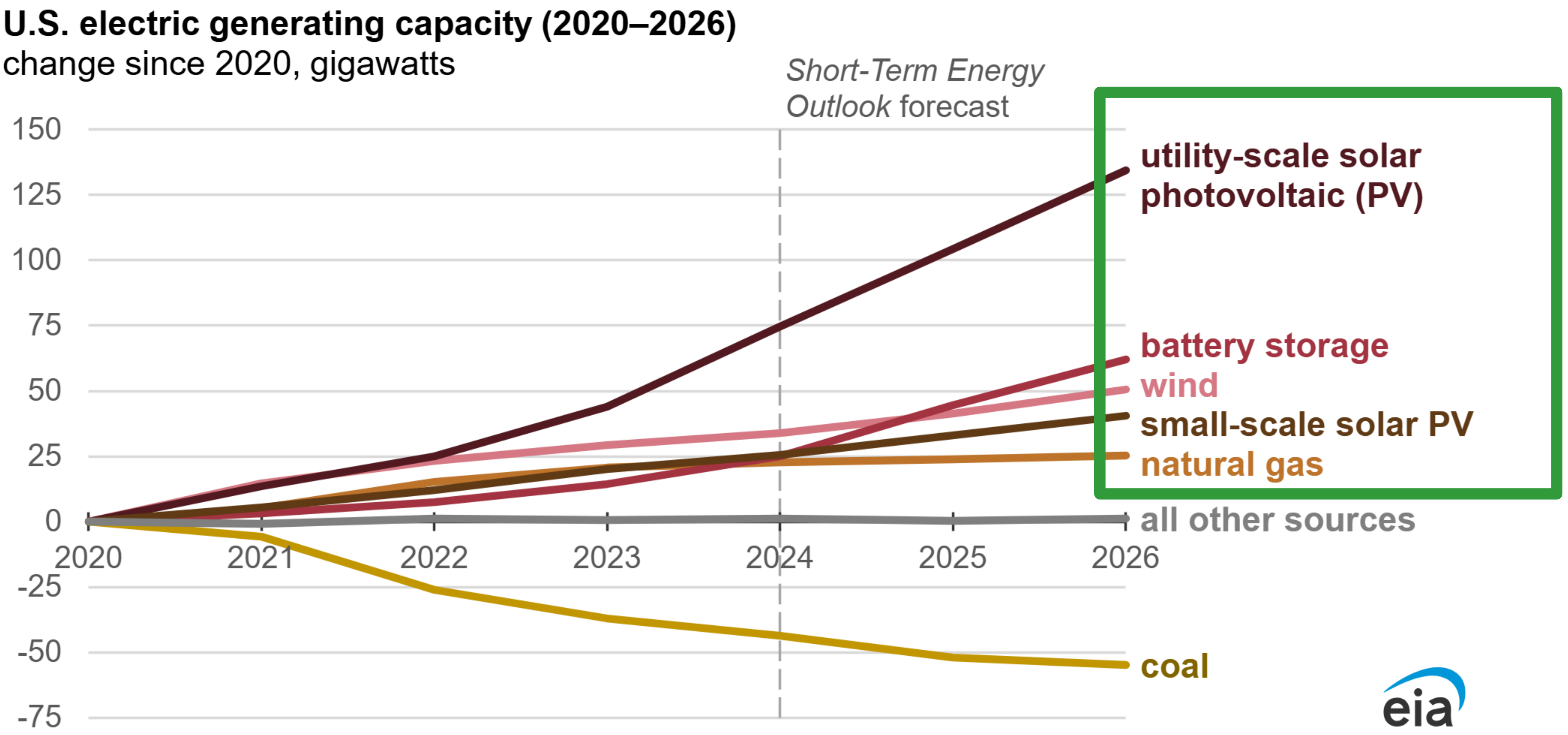
- Commercial Sector
- Information Technology
- Fleets and Transportation
- Residential Sector
- Manufacturing Sector



Demand is **Rising**

Source: U.S. Energy Information Administration, *Monthly Energy Review* and *Short-Term Energy Outlook*, May 2025

PV, Wind, and Battery Storage

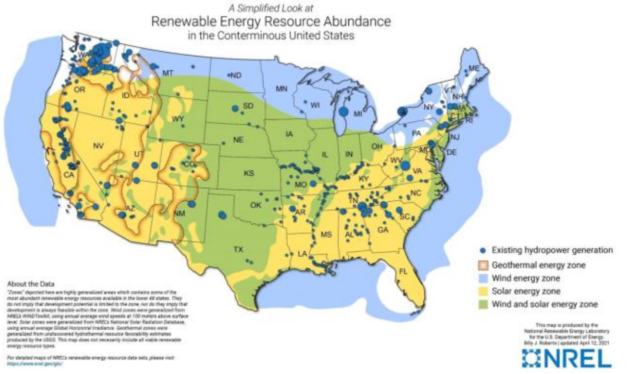


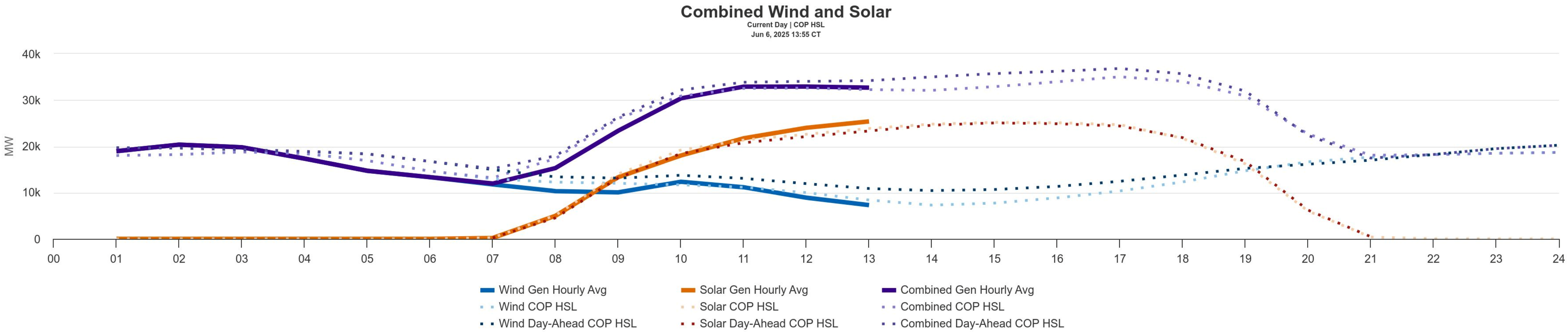
Source: U.S. Energy Information Administration, *Short-Term Energy Outlook*, May 2025

PV, Wind, and Battery Storage

Often Grouped together:

- Most prevalent sources of onsite renewable generation
- PV and wind have complementary generation profiles





Solar Energy

Solar Energy Technologies

Electricity
- Photovoltaic (PV)
- Concentrated Solar Power (CSP)

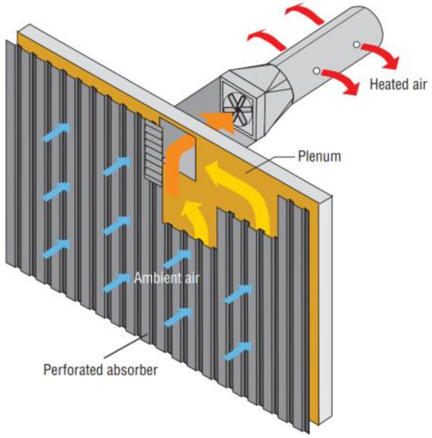
Thermal Applications
- Solar Hot Water Systems
- Solar Space Heating and Cooling
- Solar Process Heat

Solar PV

CSP

Evacuated Tube Solar Hot Water Collectors (up to 750ºF)

Parabolic Solar Trough



Transpired Air Collectors
(Solar preheating for ventilation air)

Solar Resource

- **Irradiance:** Incoming solar radiation received per unit area (W/m²)
- **Direct Normal Irradiance (DNI)**: Solar radiation received directly from the sun on a surface perpendicular to the sun's rays; used for concentrating solar power systems.
- **Diffuse Horizontal Irradiance (DHI)**:Solar radiation scattered by the atmosphere and received from all directions on a horizontal surface (equally).
- **Global Horizontal Irradiance (GHI)**:Total solar radiation received on a horizontal surface, including both DNI (projected) and DHI (scattered)

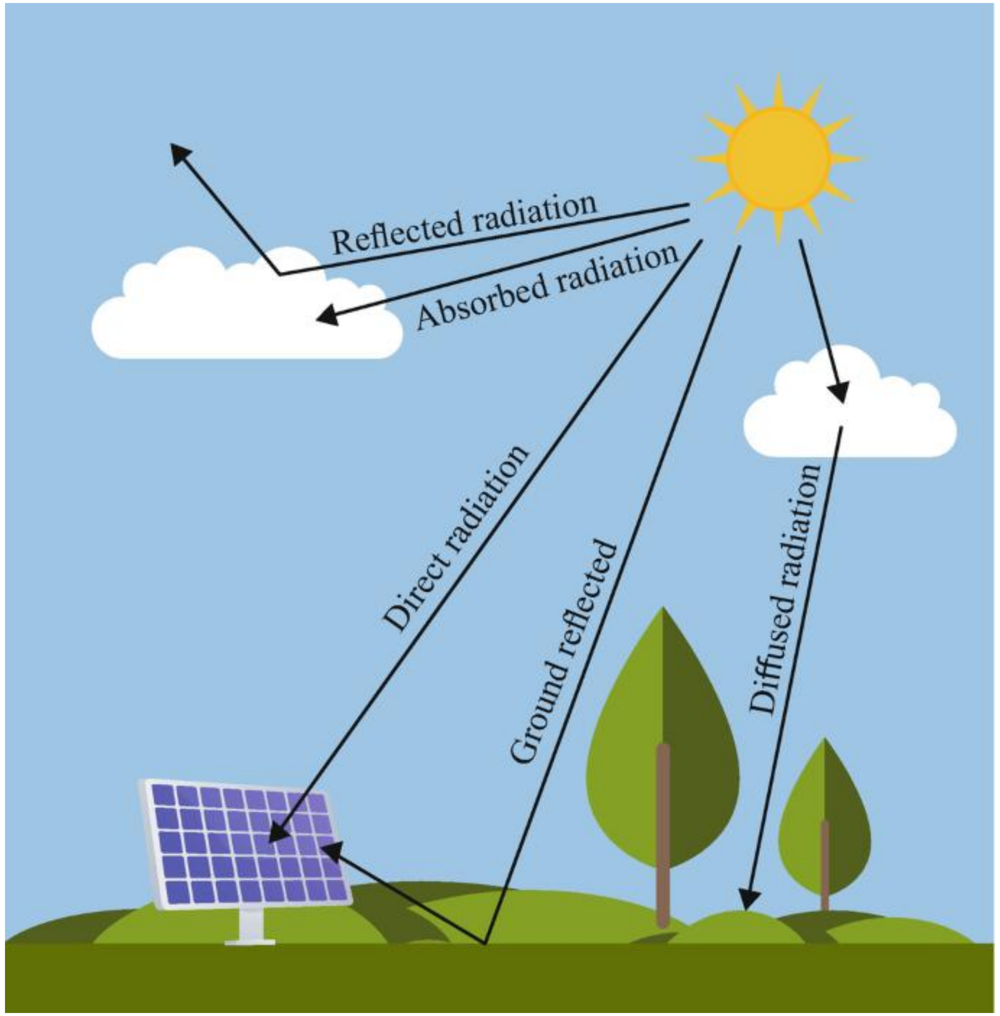
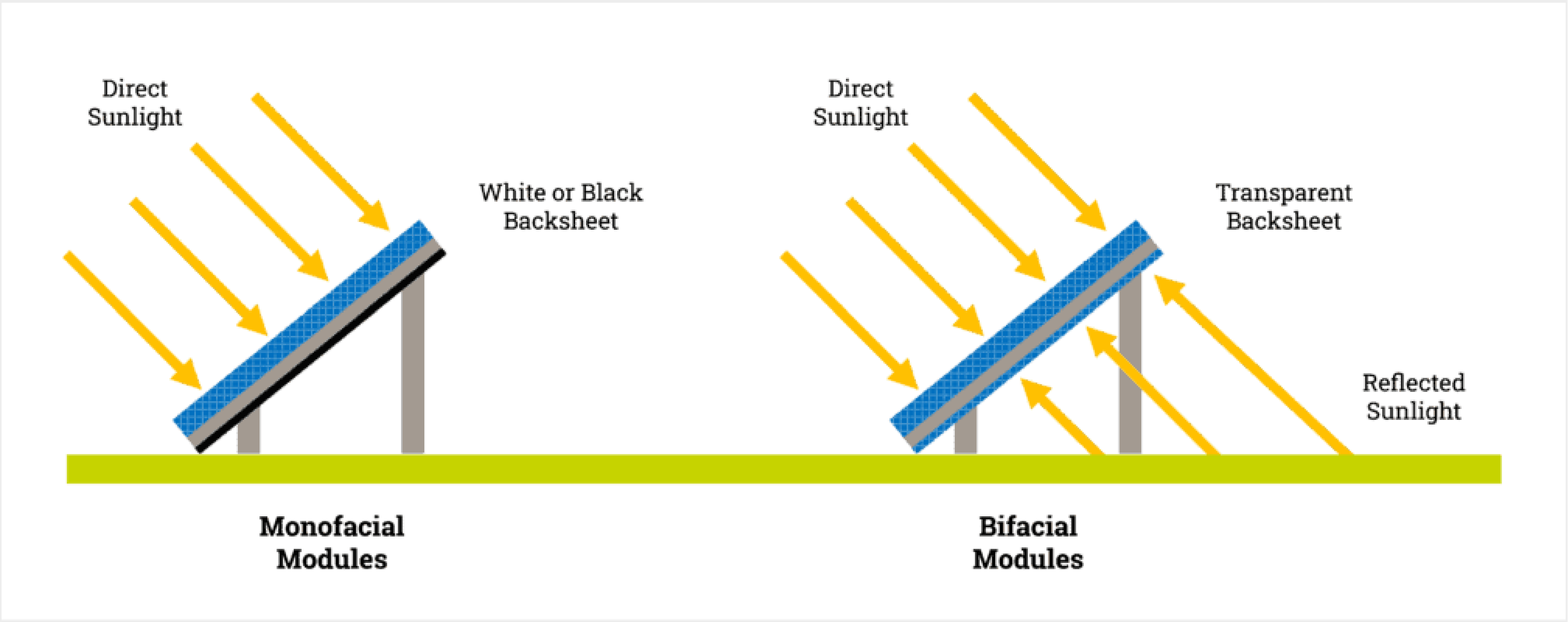


Image Source: Abou Jieb, Y., Hossain, E. (2022). Solar Resources. In: Photovoltaic Systems. Springer, Cham. https://doi.org/10.1007/978-3-030-89780-2_4

PV Cells


Direct
Sunlight
White or Black
Backsheet
Monofacial
Modules
Direct
Sunlight
Transparent
Backsheet
Reflected
Sunlight
Bifacial
Modules

How Solar PV Technology Works?

- Concept
- Main components
  - Panels
  - Inverter
  - Battery
  - Distribution
- Nameplate capacity rating (kW_{dc} & kW_{ac})

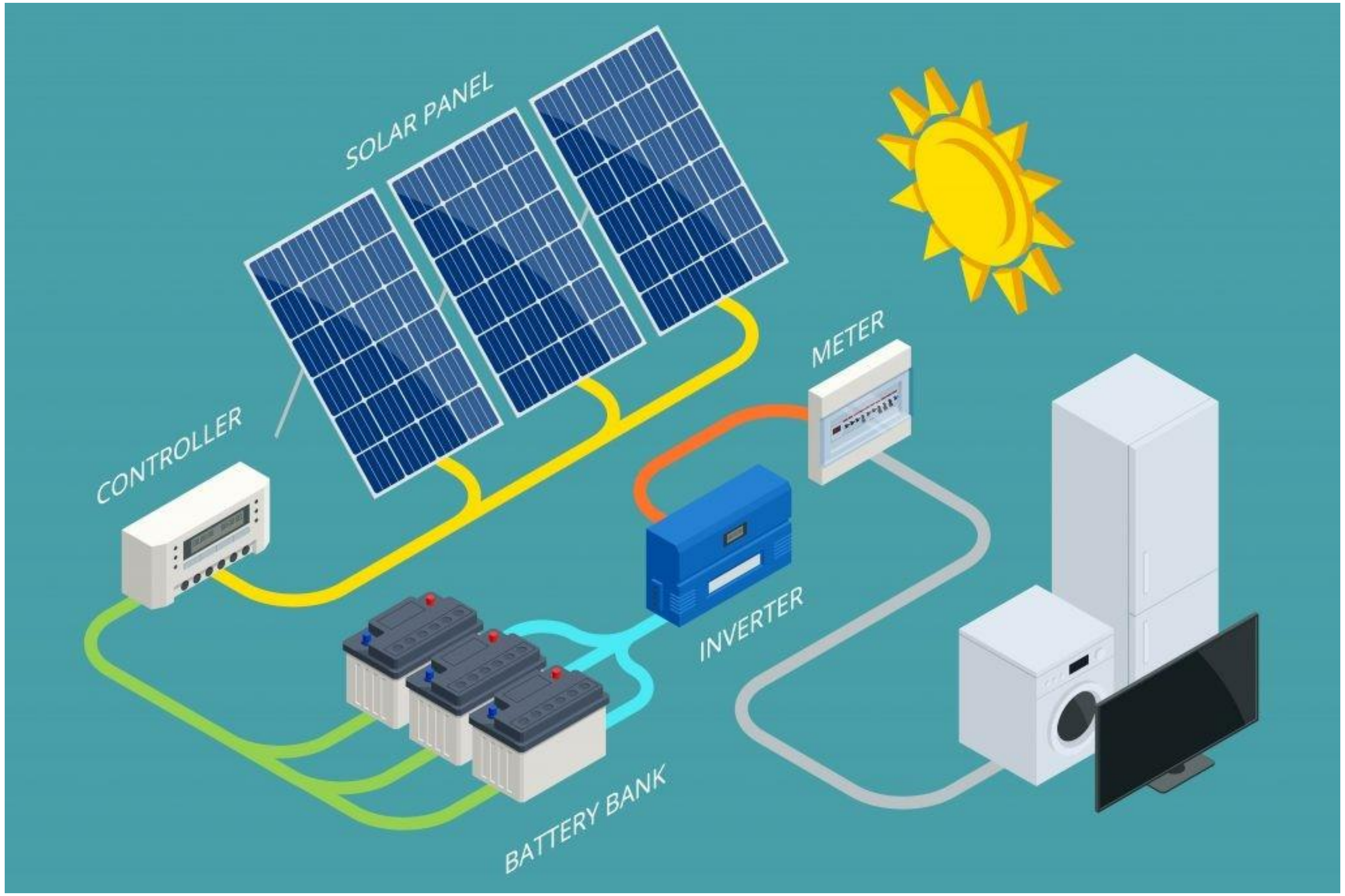
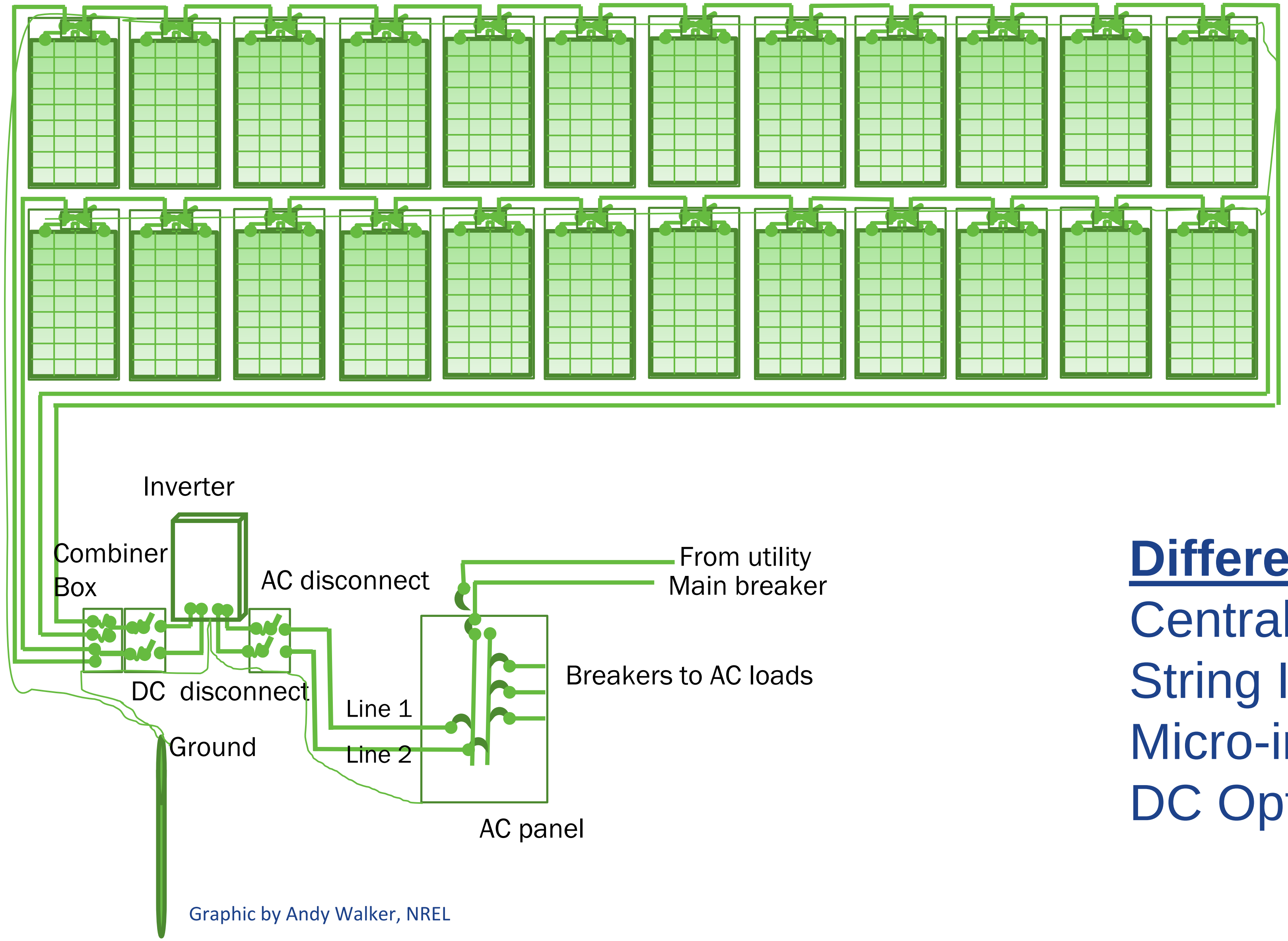


Image Source: https://www.linkedin.com/pulse/what-solar-energy-how-do-panels-work-blue-jay-technology-co-ltd/

Alternating Current (AC) PV System with Inverter

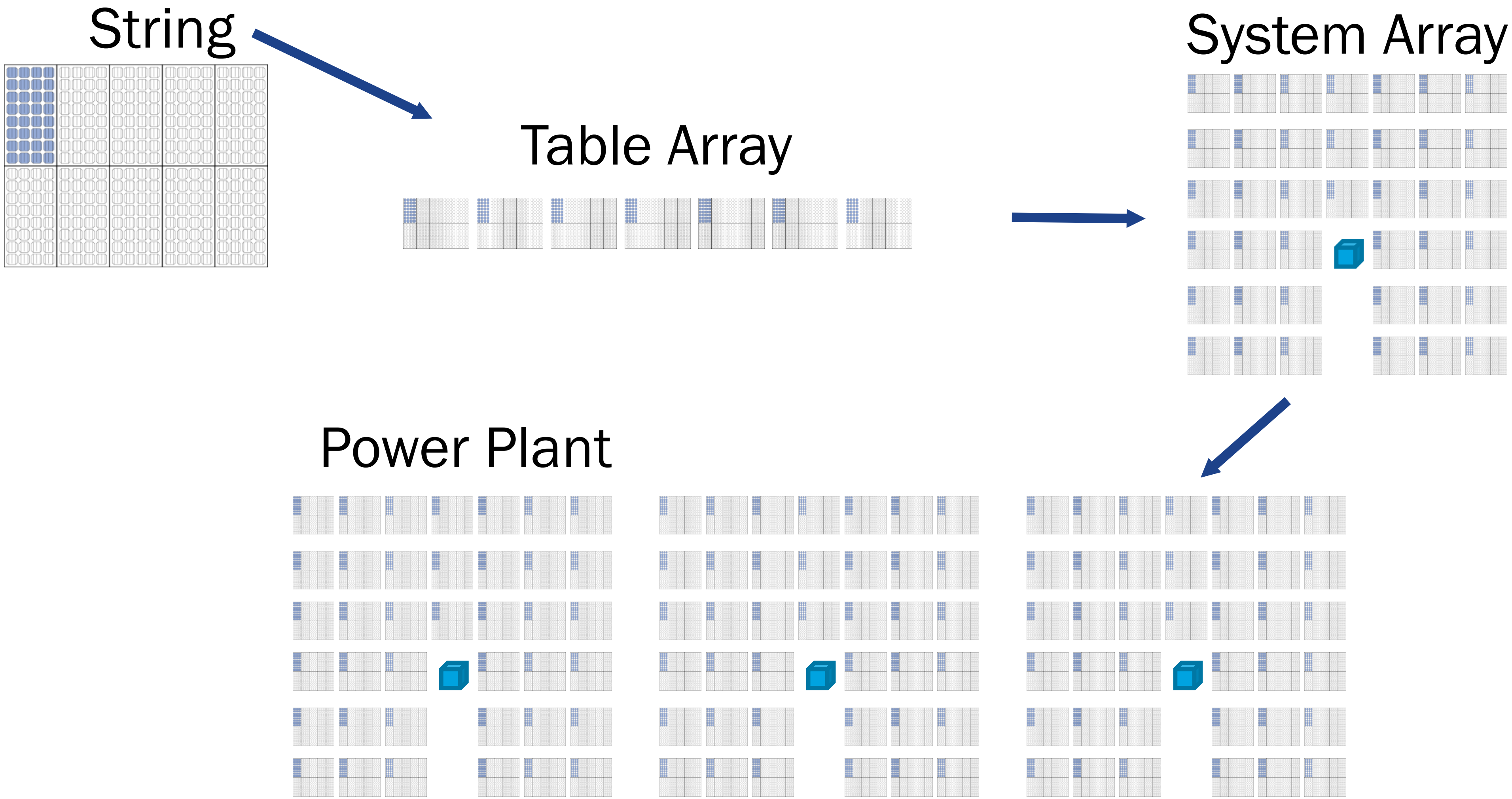


Graphic by Andy Walker, NREL

Different Inverter Arrangements:

Central Inverter
String Inverter
Micro-inverter (on each PV Module)
DC Optimizer

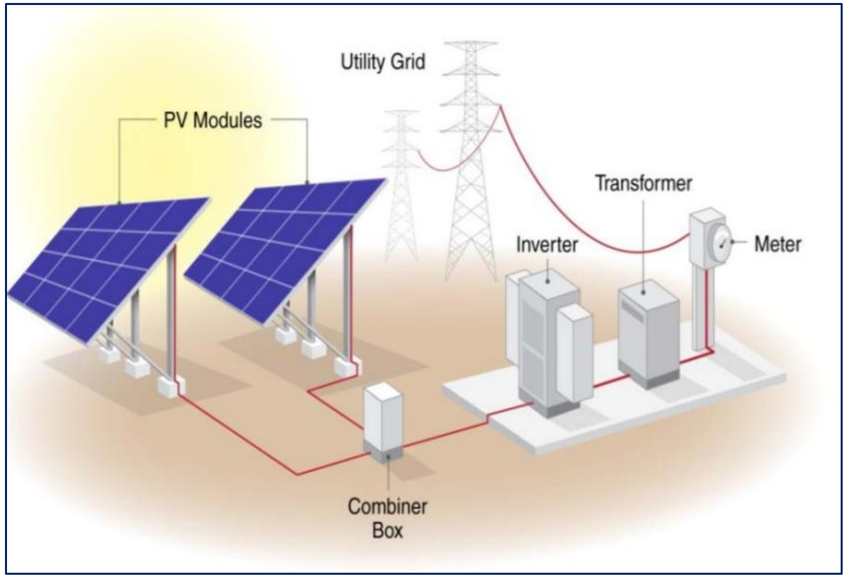
Solar PV is Modular



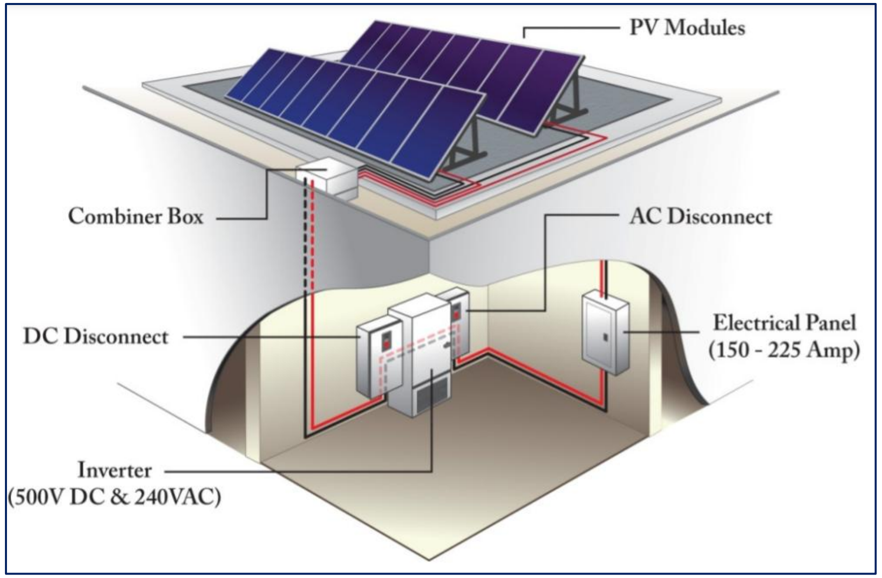
Adapted from Andy Walker, NREL

Type of Solar PV Installations

1. Distributed Generation (Distributed Energy Resources, DER)
   a) Residential (3 - 10 kW)
   b) Commercial/Industrial (10 kW - 2 MW)
2. Utility-scale Generation (> 2 MW)



Ground Mounted



Rooftop Mounted

Source: NREL, 2016. Facility-Scale Solar Photovoltaic Guidebook

Type of Solar PV Orientations

Fixed Tilt

Image Source: PVCase.com

Single-Axis Tracker

Image Source: Arctech

Now with Bi-Facial Panels

Type of Solar PV Orientations: Dual-Axis

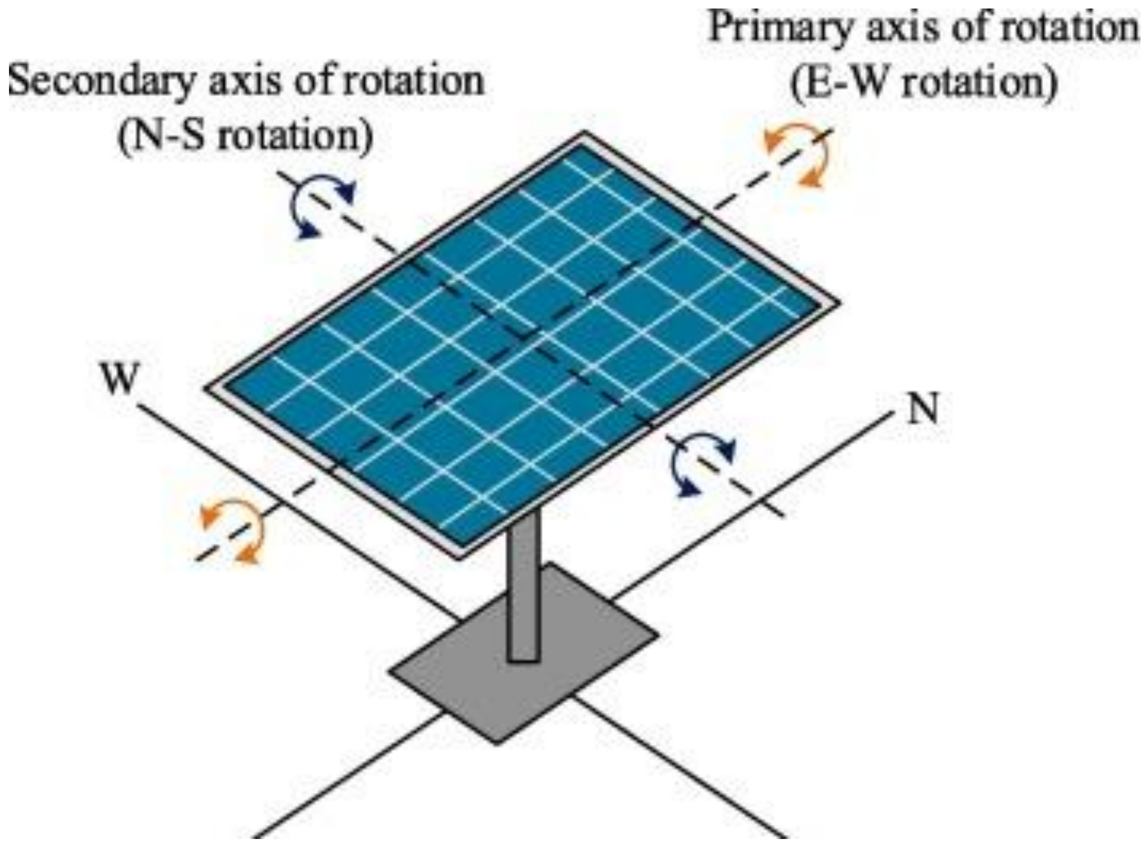


Image Source: Chaowanan et al. 2020 https://doi.org/10.1016/j.seta.2019.100618.

Image Source: https://www.solarcentex.com/

Type of Solar PV Orientations: Vertical

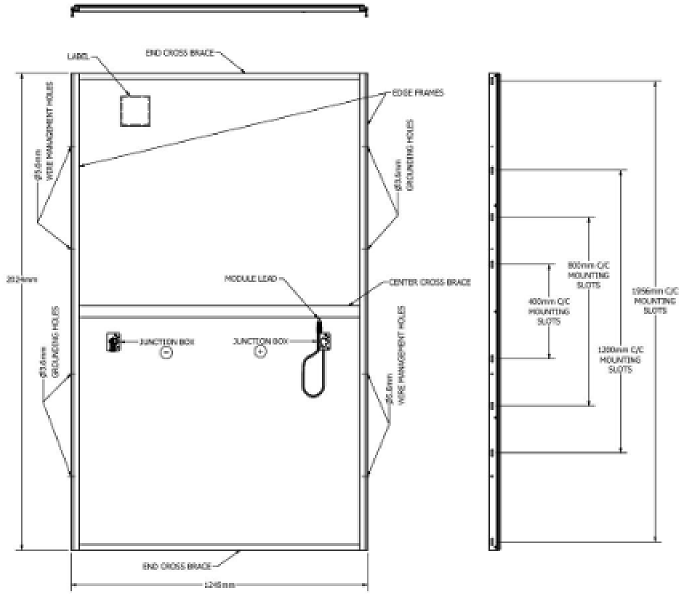
With Bi-Facial Panels

Image Source: PVMagazine

Image Source: Next2Sun

PV Module Nameplate

Mechanical Specifications



Series 6 Plus.

Electrical Specifications

RATINGS AT STANDARD TEST CONDITIONS (1000W/m², AM 1.5, 25°C)[2]							
SERIES 6 PLUS SL MODEL TYPES: FS-6XXX-P-I / FS-6XXXA-P-I							
SERIES 6 PLUS HL MODEL TYPES: FS-6XXX-P / FS-6XXXA-P (XXX = NOMINAL POWER)							
Nominal Power[3] (-0/+5%)	P_{MAX} (W)	455	460	465	470	475	480
Efficiency (%)	%	18.1	18.3	18.5	18.7	18.9	19.0
Voltage at P_{MAX}	V_{MAX} (V)	187.8	188.8	189.8	191.1	191.5	192.8
Current at P_{MAX}	I_{MAX} (A)	2.42	2.44	2.45	2.46	2.48	2.49
Open Circuit Voltage	V_{OC} (V)	222.0	222.9	223.8	224.3	224.8	225.4
Short Circuit Current	I_{SC} (A)	2.58	2.59	2.60	2.61	2.61	2.62
Maximum System Voltage	V_{SYS} (V)	1500[5]					
Limiting Reverse Current	I_R (A)	5.0					
Maximum Series Fuse	I_{CF} (A)	5.0					
RATINGS AT NOMINAL OPERATING CELL TEMPERATURE OF 45°C (800W/m², 20°C AIR TEMPERATURE, AM 1.5, 1m/s WIND SPEED)[2]							
Nominal Power	P_{MAX} (W)	343.6	347.3	351.3	355.0	358.8	362.4
Voltage at P_{MAX}	V_{MAX} (V)	176.2	176.3	177.4	179.3	179.4	180.3
Current at P_{MAX}	I_{MAX} (A)	1.95	1.97	1.98	1.98	2.00	2.01
Open Circuit Voltage	V_{OC} (V)	209.6	210.4	211.3	211.8	212.3	212.7
Short Circuit Current	I_{SC} (A)	2.08	2.09	2.10	2.10	2.11	2.11

TEMPERATURE CHARACTERISTICS		
Module Operating Temperature Range	(°C)	-40 to +85
Temperature Coefficient of P_{MAX}	T_K (P_{MAX})	-0.32%/°C [Temperature Range: 25°C to 75°C]
Temperature Coefficient of V_{OC}	T_K (V_{OC})	-0.28%/°C
Temperature Coefficient of I_{SC}	T_K (I_{SC})	+0.04%/°C

Certifications & Tests[4]

CERTIFICATIONS & LISTINGS

IEC 61215:2021 & 61730-1:2016[5], CE
IEC 61701 Salt Mist Corrosion
IEC 60068-2-68 Dust and Sand Resistance
UL 61730 1500V Listed

EXTENDED DURABILITY TESTS

IEC TS 63209-1 Extended Stress Test
Long-Term Sequential
Thresher Test
PID Resistant

QUALITY & EHS

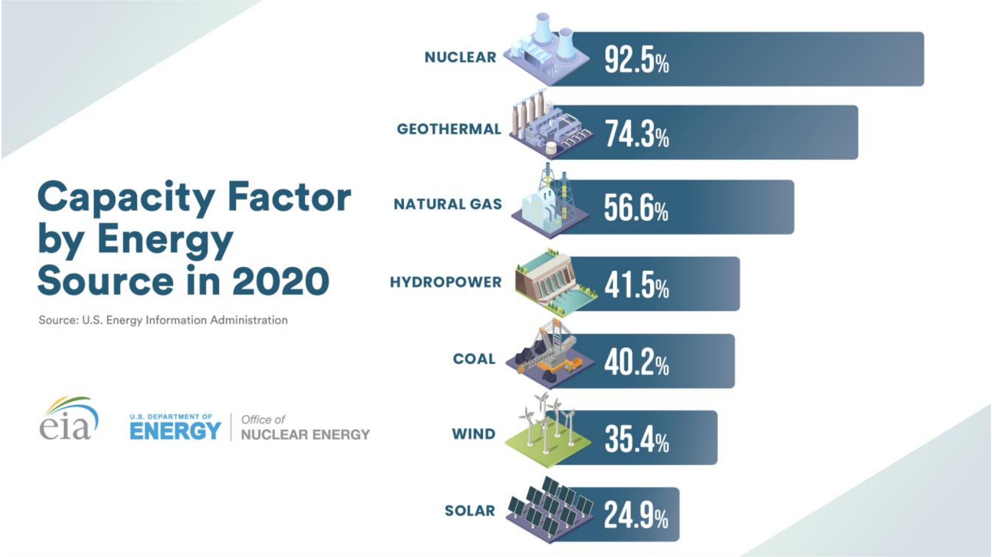
ISO 9001:2015
ISO 14001:2015
ISO 45001:2018
ISO 14064-3:2006
EPEAT Silver Registered

Source: Firstsolar

Capacity Factor (CF)

- Capacity Factor (CF) is a ratio of energy (kWh or MWh)

$$CF = \frac{actual\ electricity\ production}{modeled\ production}$$



- Capacity = Maximum Power Output (kW or MW)

Resource Based System Performance Indicator

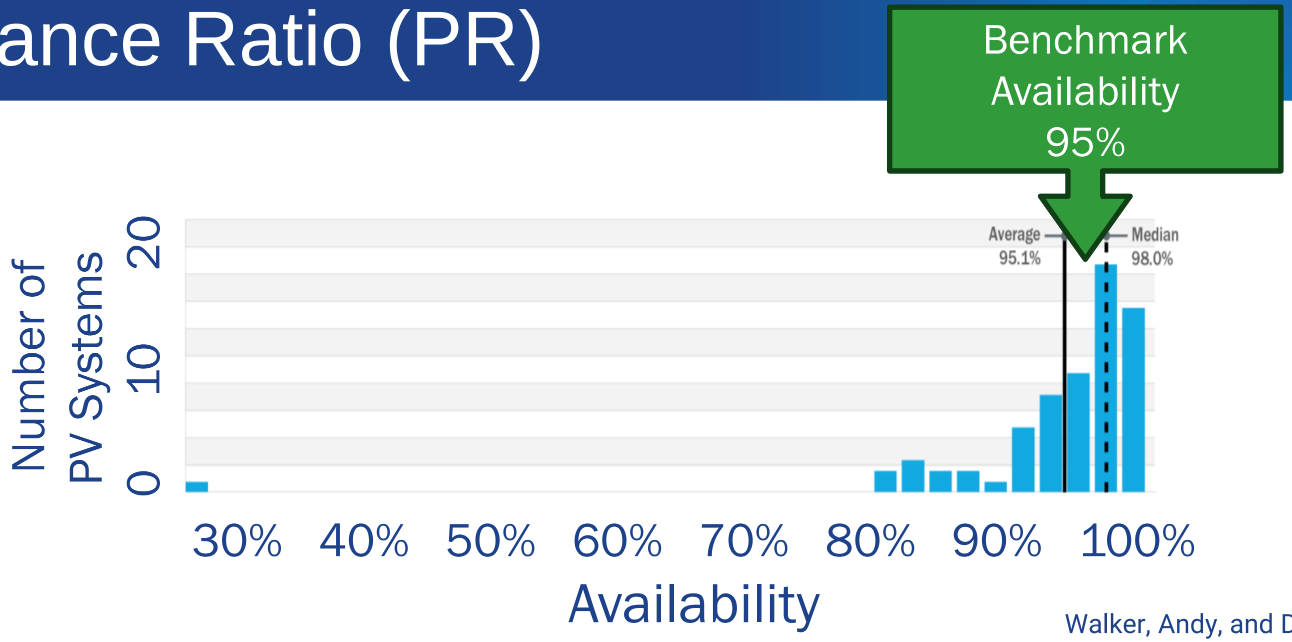
Key System Performance Indicators: Availability (A) and Performance Ratio (PR)

$$A = \frac{total\ time\ - downtime}{total\ time}$$

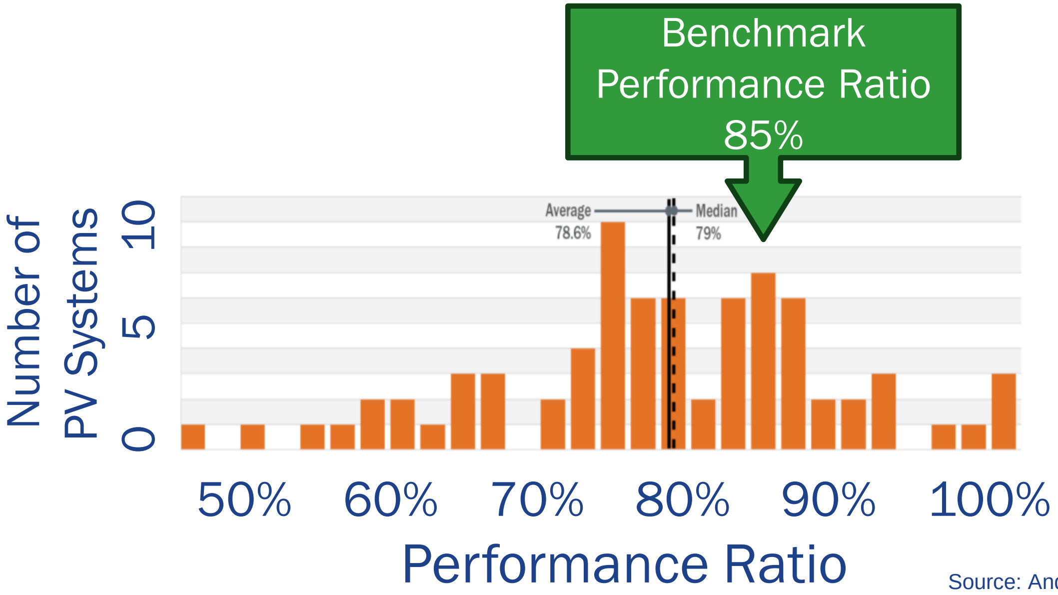
- “Information categories” for reporting status IEC 63019-1: 2019:
  - “Raw availability” versus exclusions (e.g., force majeure, utility outage, snow coverage)
  - High-resolution (e.g., hourly, daily) data and reporting required for accurate estimate of Availability

$$PR = \frac{measured\ production}{modeled\ production}$$

- Measured production
  - Production meter: 15-minute; hourly; monthly.
- Modeled production (IEC 61724-1)
  - Detailed System Description (PV modules, inverter)
  - Coincident Climate (solar and temperature) data
  - Simulation by SAM.nrel.gov or other programs



Walker, Andy, and Desai, Jal. *Understanding Solar Photovoltaic System Performance: An Assessment of 75 Federal Photovoltaic Systems*. United States: N. p., 2021. Web. doi:10.2172/1838130.



System Performance Indicators

Source: Andy Walker, NREL

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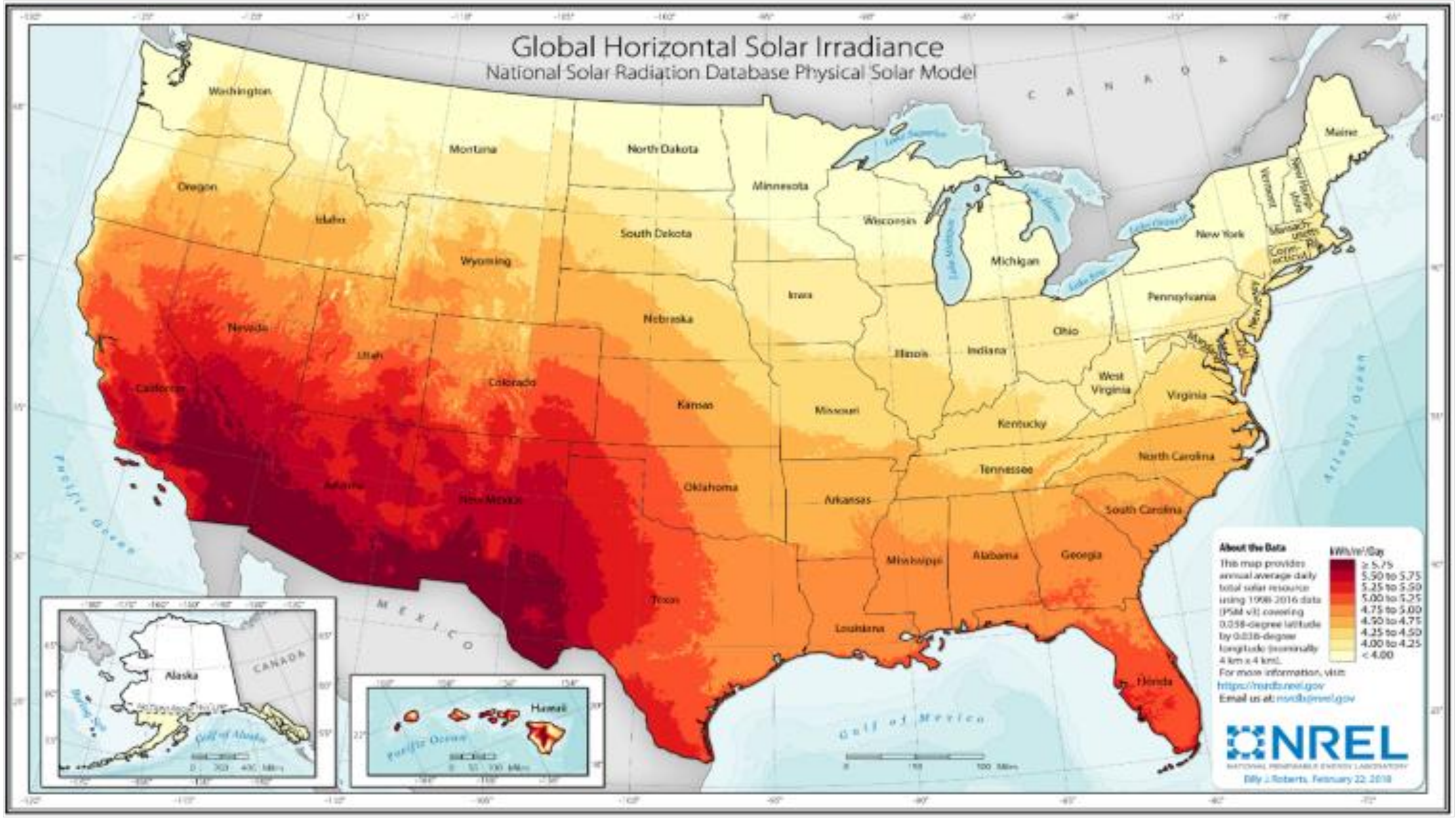
Solar PV Performance

Global Horizontal Solar Irradiance (GHI) - kWh/m²/day

GHI @ Arizona = **5.5 – 6.0** kWh/m²/day

GHI @ Minnesota = **3.0 – 3.5** kWh/m²/day

1. **Geographical location:** PV systems perform better in the Southwestern US
2. **Time of day:** Day vs night hours
3. **Season:** Summer vs winter
4. **Local landscape:** Terrain; flat plains, hills, mountains, forests.
5. **Local weather:** Number of days cloudy vs days sunny

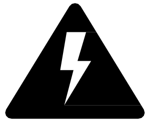


Source: NREL, 2018. NSRDB: National Solar Radiation Database

Integration of PV into Energy System

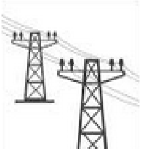
Building Level

- Sizing of Electrical System to Building
- Overcurrent Protection on Electrical Service
- Voltage Regulation
- Power Factor



Substation Level

- Substation bus arrangement, intertie

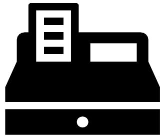


Grid Level

- Voltage Stability of Electric Grid
- Fault detection and interruption

Generation

- Ramp Rates
- Spinning Reserve



Utility Economics

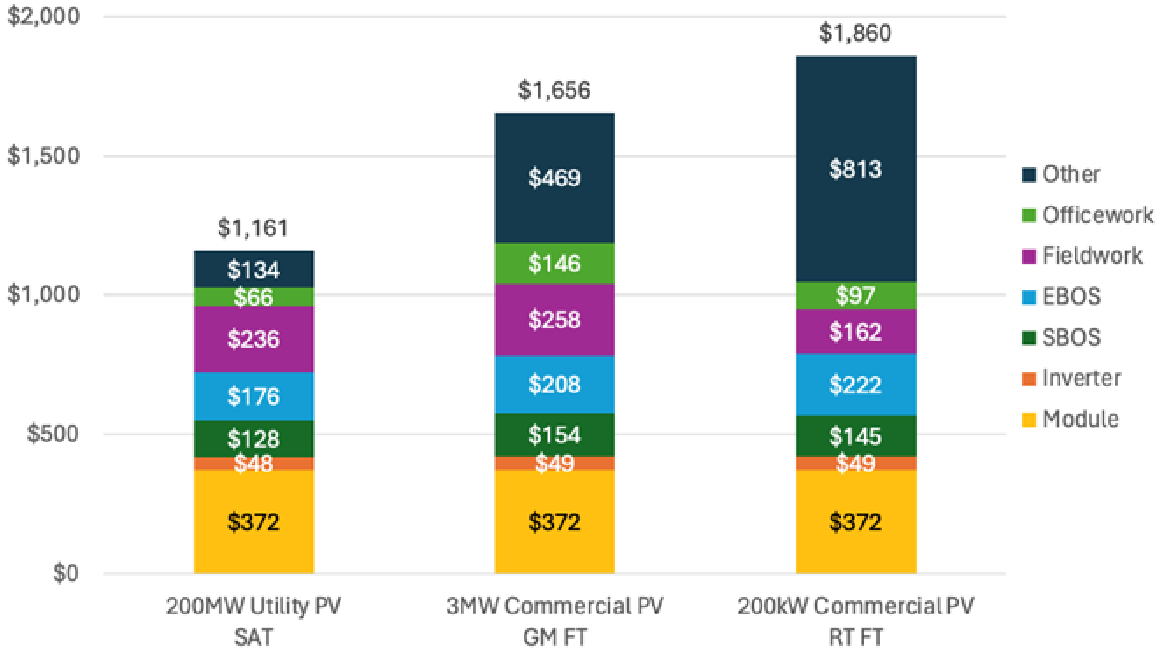
- Allocating Costs and Resources

PV Solar System Costs

Total Installed Costs for PV Systems by Scale

*Installed Costs only

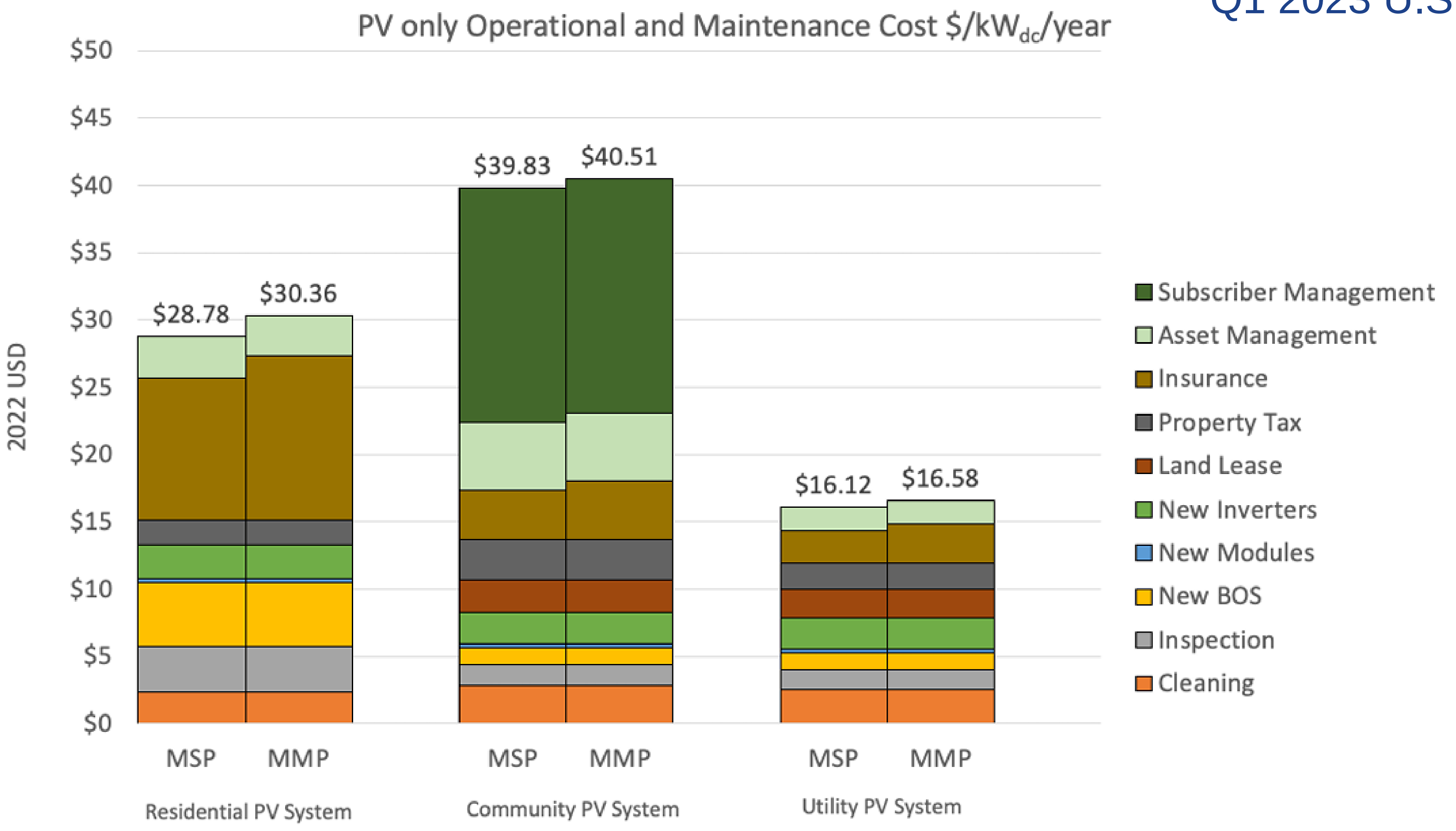
System Scale	Size	Mounting	Orientation	Cost ($/kW)
Medium Commercial / Small Industrial	200 kW	Rooftop	Fixed Tilt	$1,860
Large Commercial / Industrial	3 MW	Ground	Fixed Tilt	$1,656
			Single-Axis Tracking	$1,822
Utility	200 MW	Ground	Single-Axis Tracking	$1,161



Source: DOE Factsheets Solar Photovoltaic Panels For Industrial Applications

PV Solar System O&M Costs

Q1 2023 U.S. PV cost benchmarks



Source: Ramasamy, Vignesh, Jarett Zuboy, Michael Woodhouse, Eric O'Shaughnessy, David Feldman, Jal Desai, Andy Walker, Robert Margolis, and Paul Basore. 2023. U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2023. Golden, CO: National Renewable Energy Laboratory. NREL/TP7A40-87303. https://www.nrel.gov/docs/fy23osti/87303.pdf.

Decisions Affecting PV System Cost and Performance

- Equipment Selection
- Siting Considerations
- System Types
- Module Rack
- Inverter Topology
- Wire Management
- Vegetation

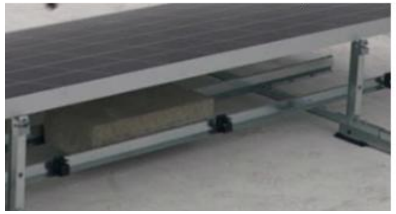

Hail Testing


Inverter Testing


Roof Mount


Ground Mount


Carport


Ballasted Rack


Attached Rack


Micro-inverter


String Inverter


Central Inverter


Wire ties


Connectors


Conduit Raceway


Direct-bury

Source: Andy Walker, NREL

Summary: Photovoltaics for Industrial Applications

- What makes a site a good fit for this technology?
  - Available area on new roof (or land area)
  - Adequate electrical service
  - High Utility Rates and Tariff Schedule Details
  - Favorable Utility, State, and Local Policies
  - Corporate goals and on-site champion
  - Adequate solar resource
- When should a site consider this technology?
  - New building or new roof project

Rules of Thumb

Cost: $1500/kW

O&M Cost: $15/kW/year

Efficiency: 20%

Roof Area: 100 sf/kW

Land Area: 3-6 Acres/MW

Energy: 1500 kWh/kW/year

Capacity Factor: 0.17

Hours/day: 5 hours

Performance Ratio: 85%

Source: Andy Walker, NREL

5 Minute Break

Wind Energy

U.S. DEPARTMENT OF ENERGY

Brief History of Wind Turbines

Mechanical Power → Electrical Power

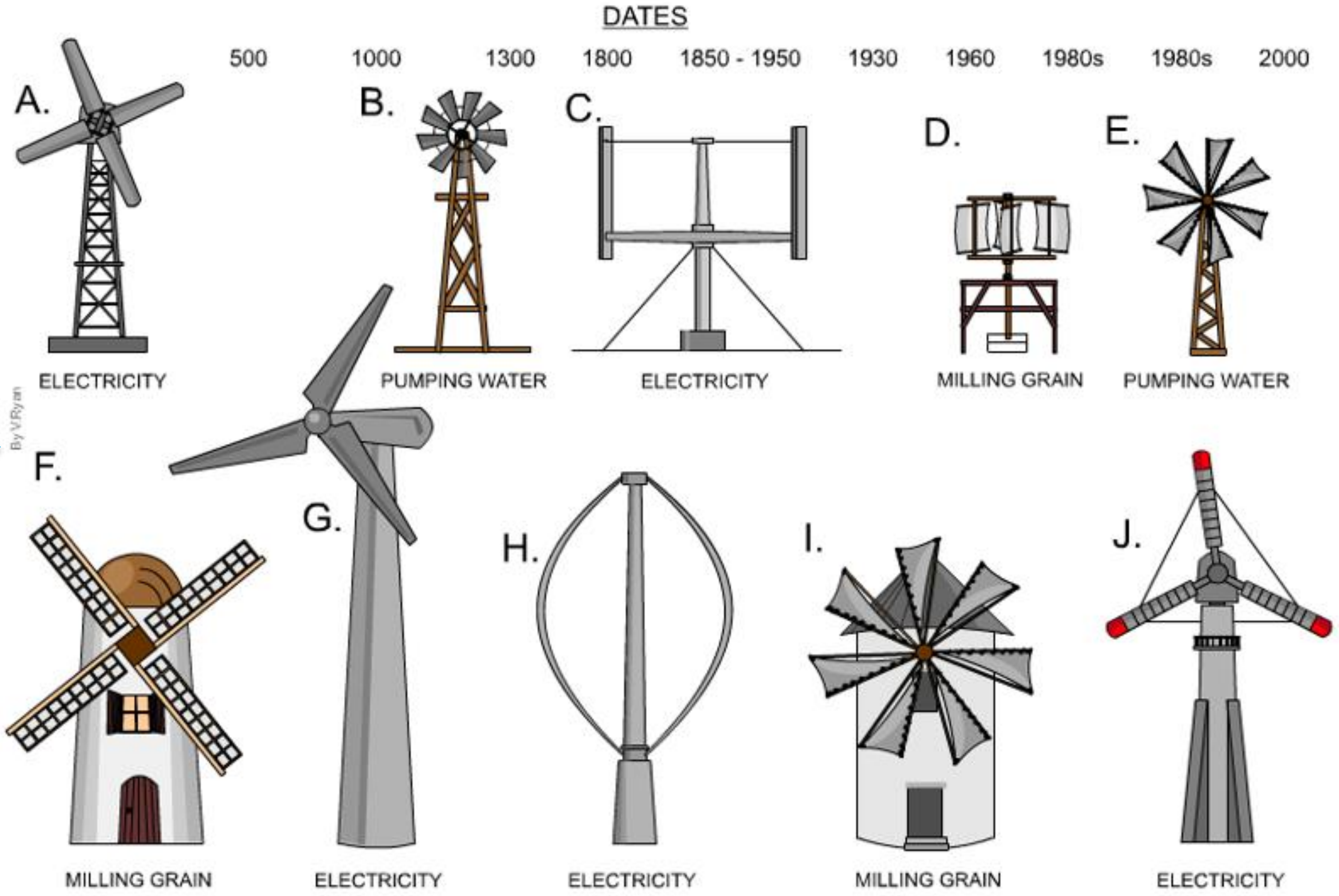


Image Source: technologystudent

Wind Energy Technologies

System Variations

- Axis orientation
- Tower height
- Rotation capabilities
- Blade counts and orientations

Horizontal Axis Wind Turbine

Vertical Axis Wind Turbine

Increasing Hub Heights

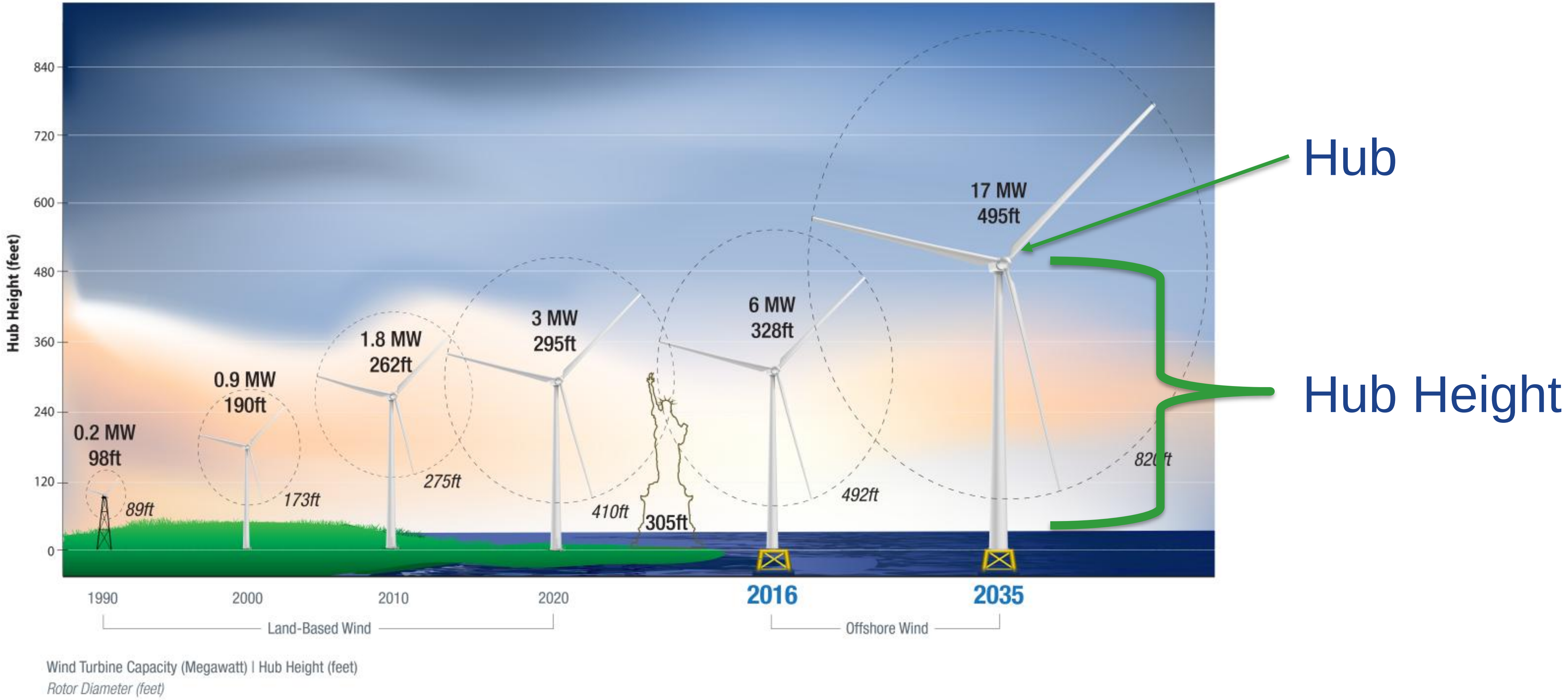
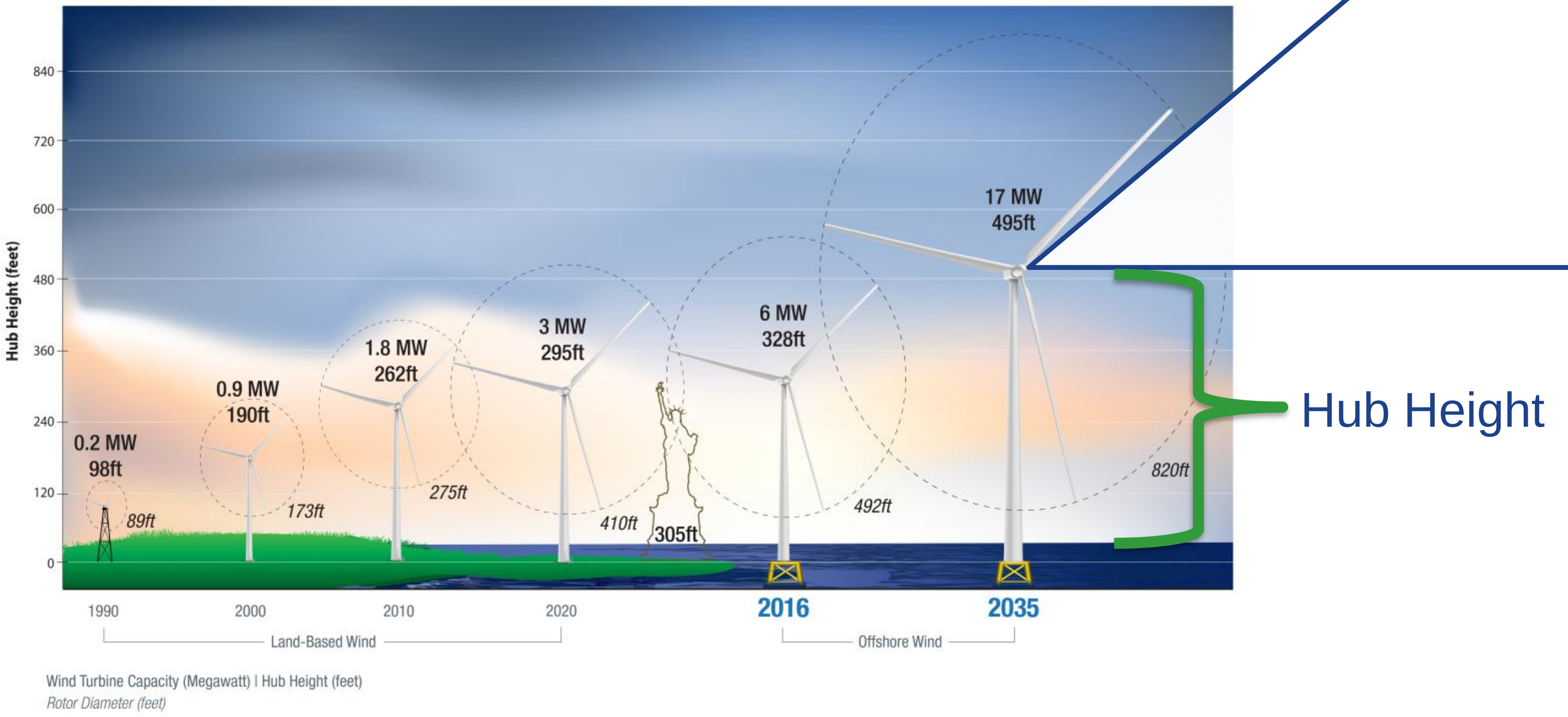


Image Source: DOE

Hub and Nacelle



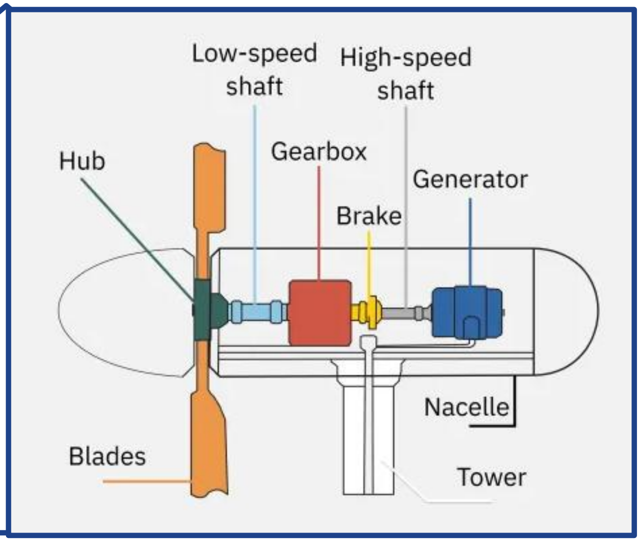


Image Source: U.S. DOE, Wind Energy Technologies Office (2023) "How a Wind Turbine Works - Text Version". https://energy.gov/eere/wind/inside-wind-turbine-0, Flaticon

Wind Turbines Operation

- The rotor (hub and rotor blade assembly) captures wind that creates torque (rotational force) that spins a low-speed shaft
- The gearbox increases the shaft speed which turns a generator
- The generator produces electricity
- Multiple turbines are connected to form a wind farm
  - Wind farm design should consider turbine to turbine spacing

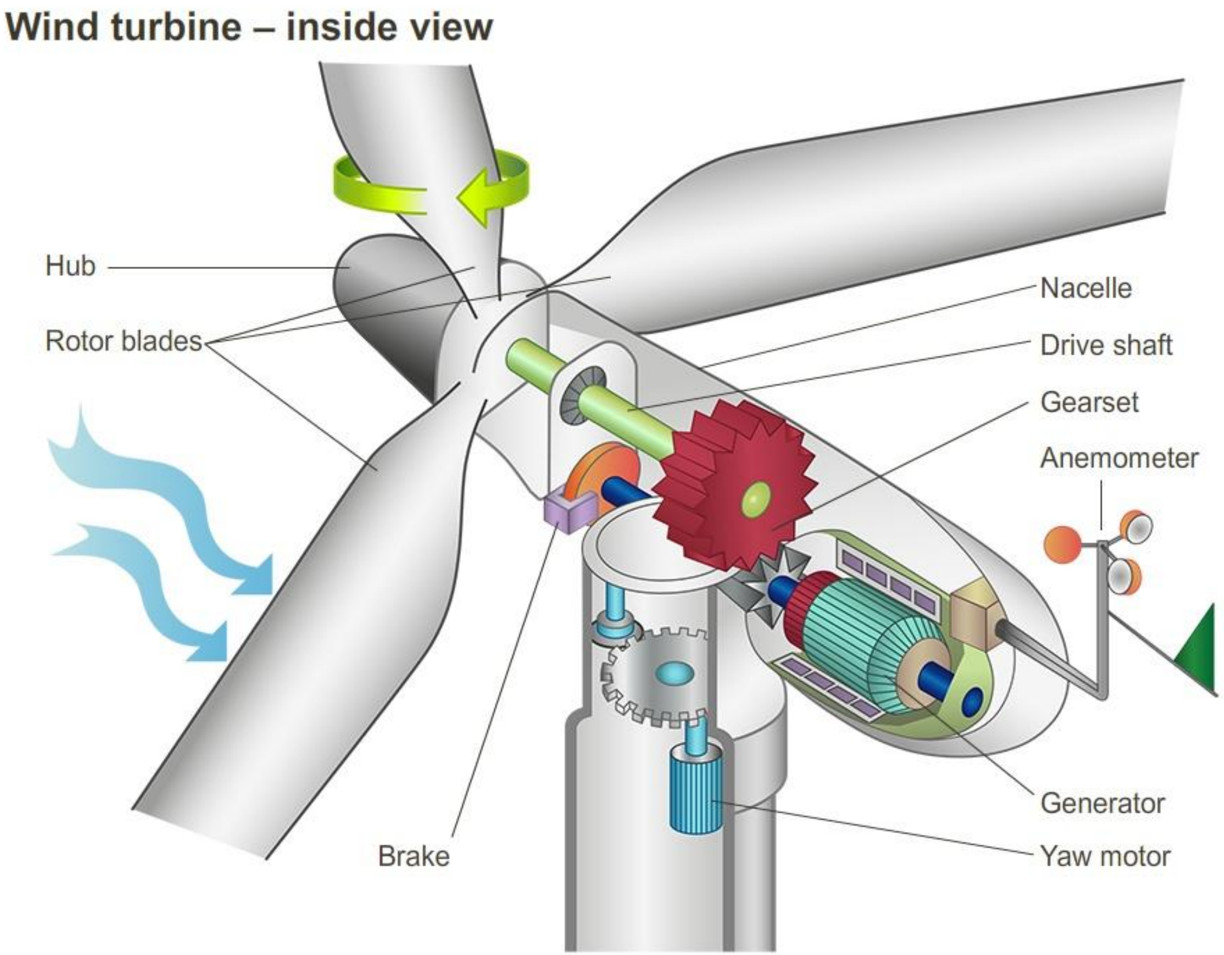
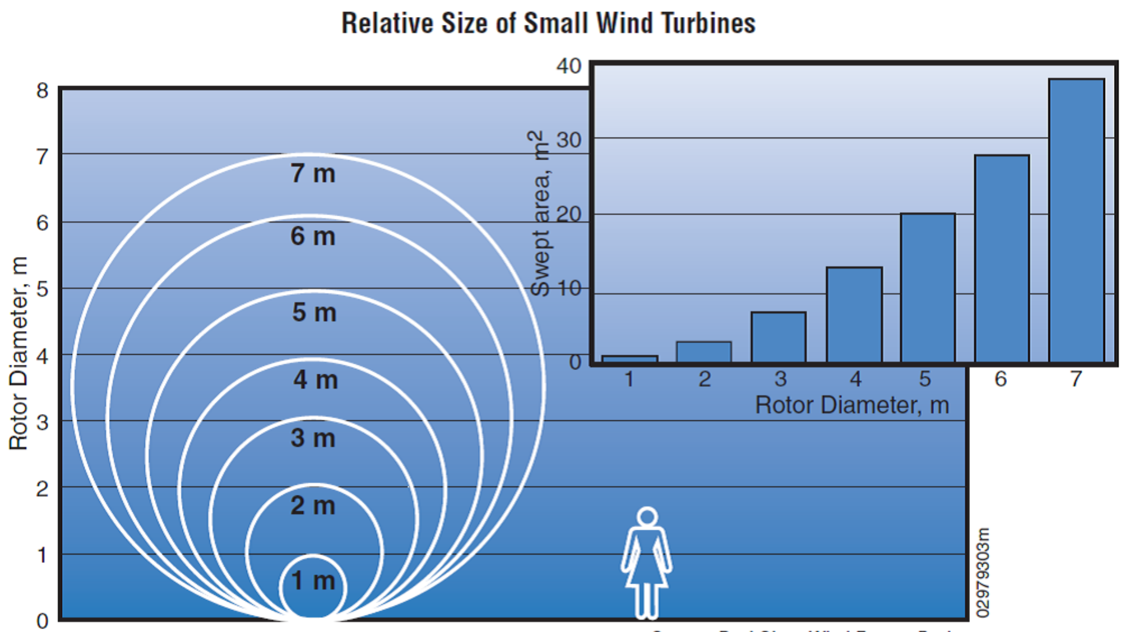


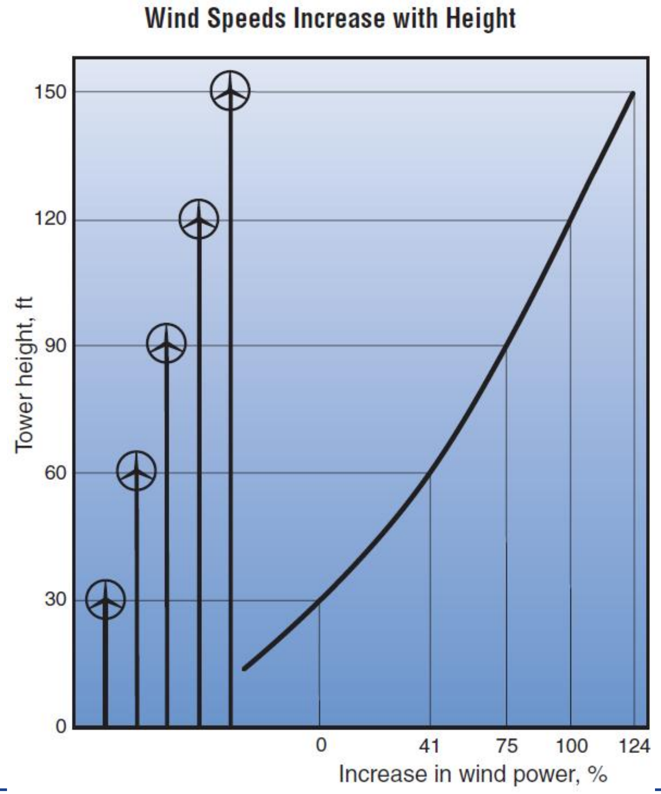
Image Source: Siemens Stiftung Media Portal

Wind Turbines Operation

- Size of the Blades ~ **Wind-Swept Area = More Energy**
- Generator Capacity = **Rating (kW or MW)**



Source: Paul Gipe, *Wind Energy Basics*

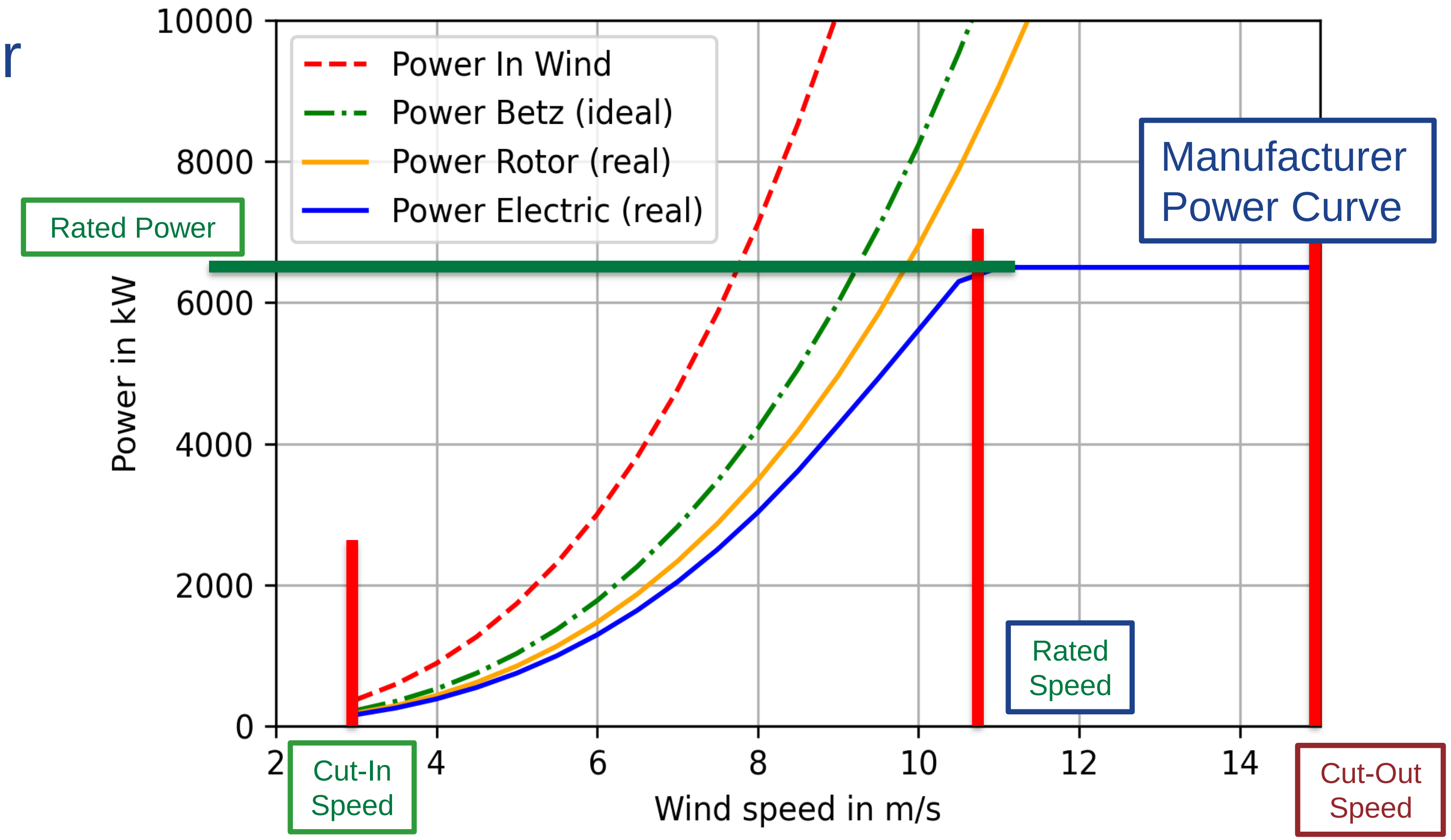


Wind Power Curve

- Below Rated Speed
  - Operate at maximum power coefficient
  - Optimum power tracking

- Above Rated Wind Speed
  - Limit power output to grid
  - Limit turbine loads

Power increases with the cube of the wind speed



Source: Jennifer King, NREL

Wind Turbines: Specific Power

$$\textit{Specific Rating} \text{ or } \textit{Specific Power} = \frac{\textbf{Generator Size}}{\textbf{Blade Size (Wind Swept Area)}}$$

High Specific Power (HSP)

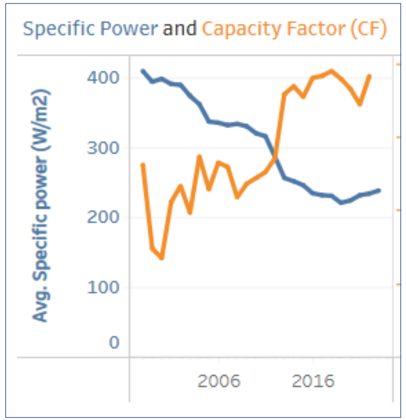
Large Blades, Large Generators

Generally economic, lower LCOE

Low Specific Power (LSP)

Generator Size

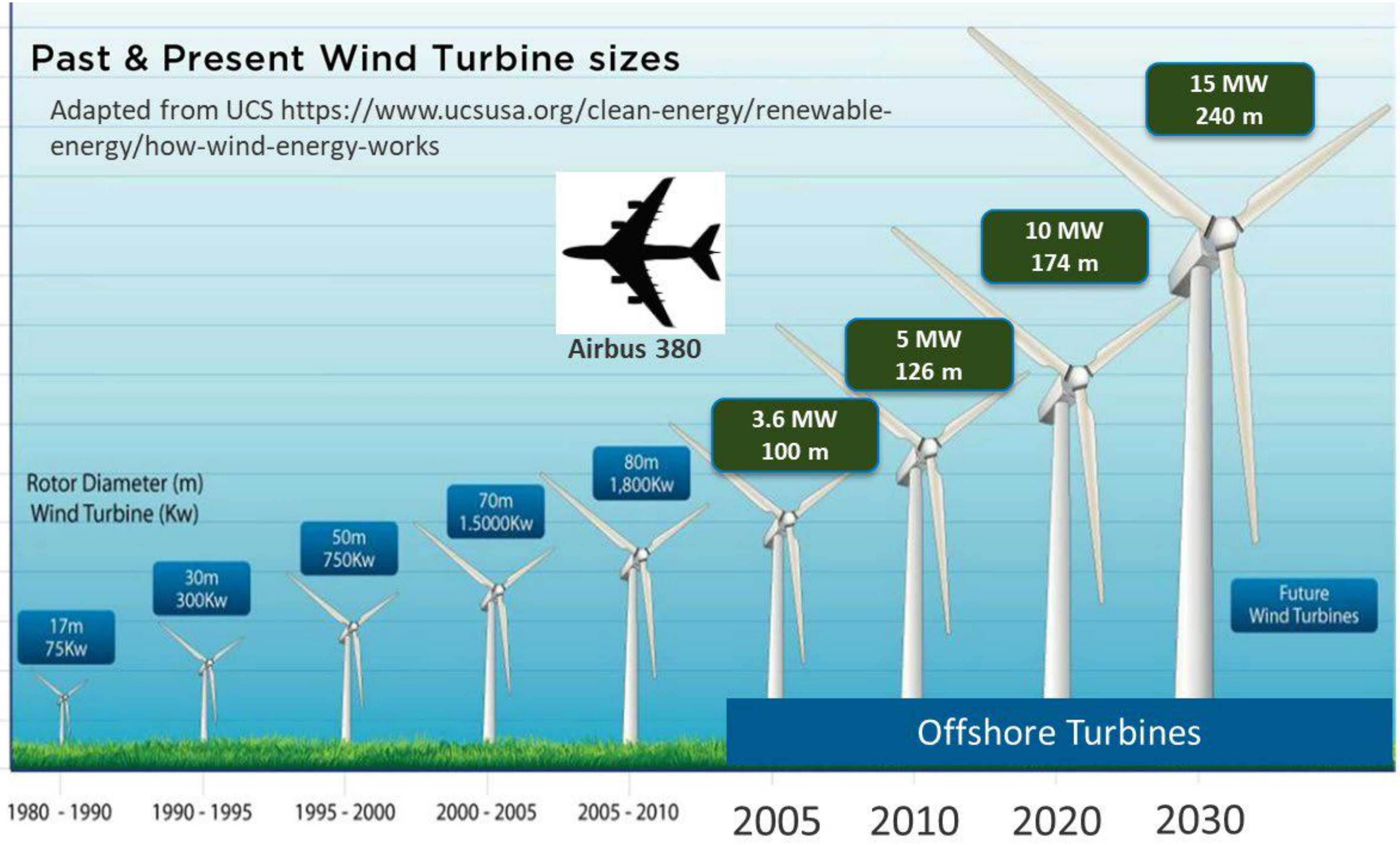
Blade Size



Sources: Jennifer King (NREL), Berkeley Labs

Wind Turbine Size

- Transportation constraints for land- based deployment
- Offshore turbines are much larger than land-based turbines
- Fewer installation and transportation constraints offshore
- Larger turbines lower project costs
  - Fewer turbines are cheaper to maintain
  - Wind speeds higher at taller heights
- No hard limits to further turbine growth*



Source: NREL, https://www.nrel.gov/docs/fy07osti/42005.pdf

Siting Wind Power

Shared Infrastructure will help with project costs and delivery

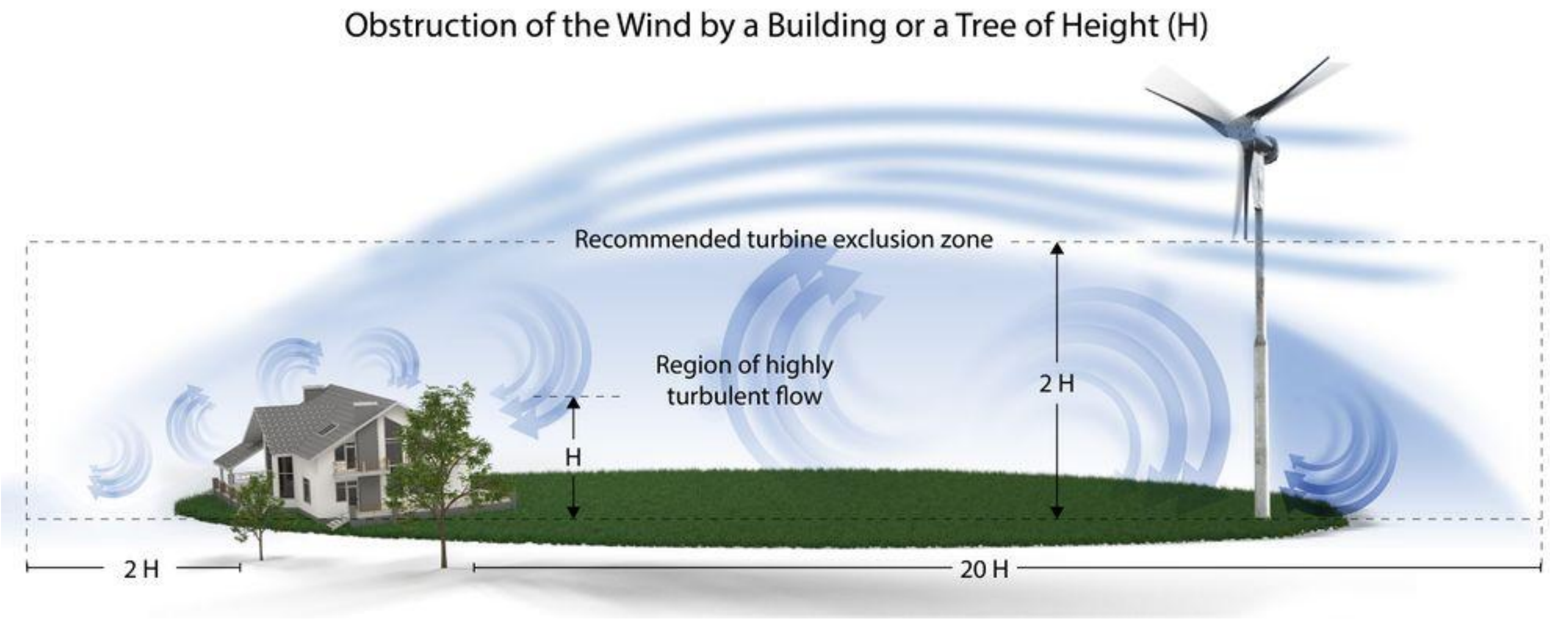
Rule of thumb:
1.1 Times Tip Height (top of blade) exclusion

Location Considerations

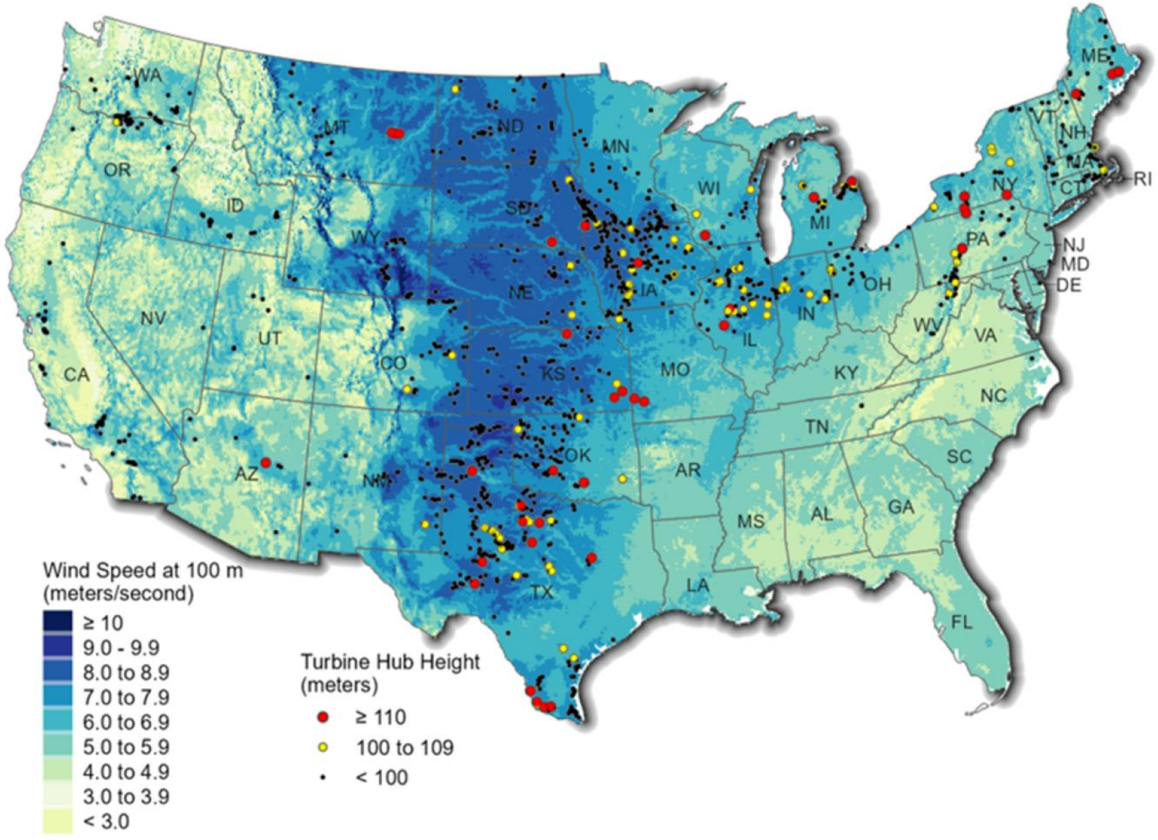
- Load Proximity
- Local Zoning and Regulations
- Community Stakeholders
- Maintenance Access
- Interconnection and Grid

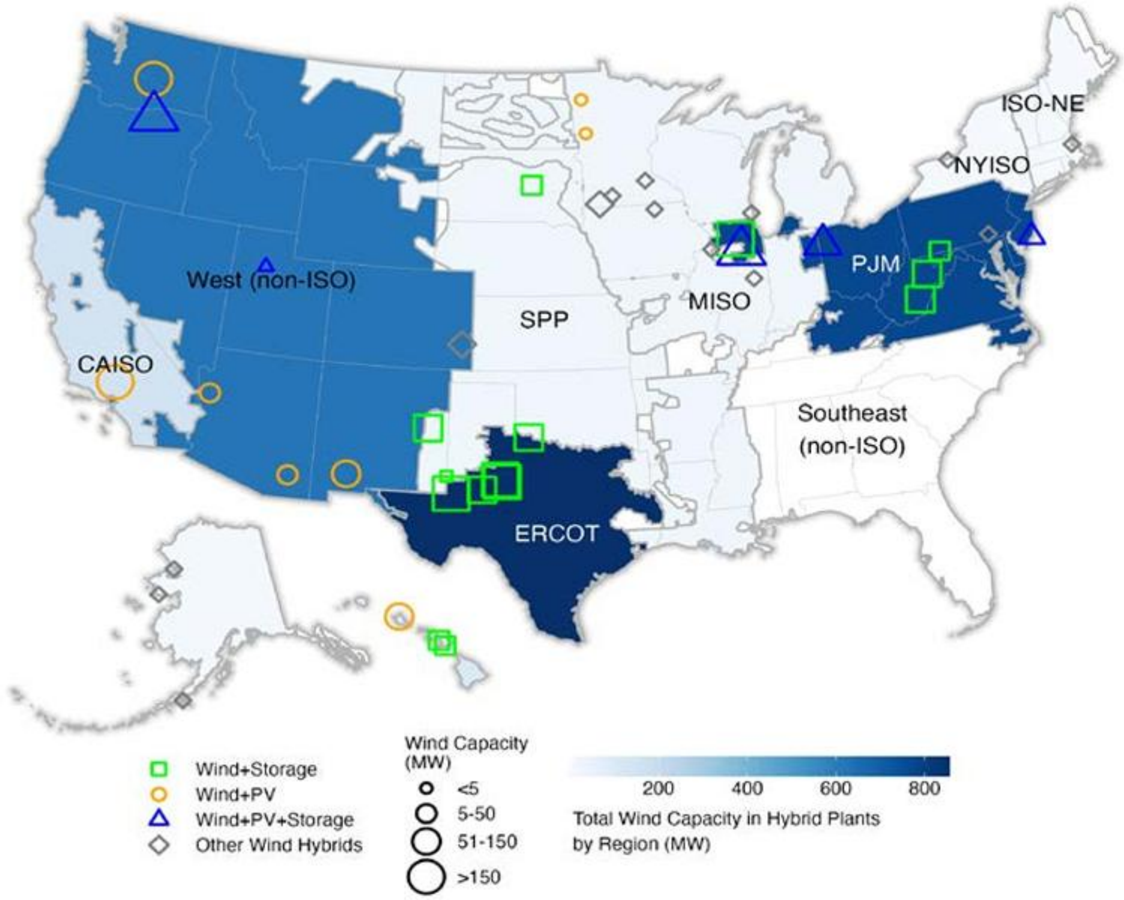
Setbacks

- Roads
- Property Lines
- Noise
- Wildlife and Airspace
- Radar Interference



Wind in USA

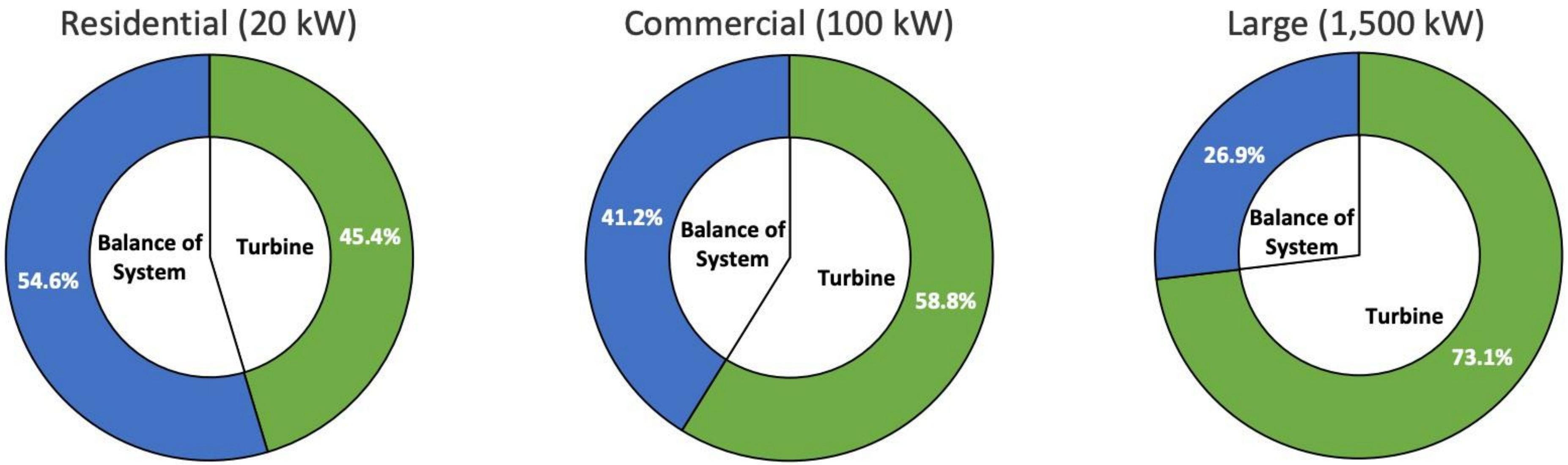




Sources: EIA-860 2022 Early Release, Berkeley Lab

Sources: ACP, U.S. Wind Turbine Database, AWS Truepower, Berkeley Lab, ***Land-Based Wind Market Report: 2024 Edition***

Distributed Wind Costs



Parameter	Wind Turbine Class			Units
	Residential	Commercial	Large	
Wind turbine CapEx	3,823	3,723	2,392	$/kW
BOS CapEx	4,602	2,604	878	$/kW
Total CapEx	8,425	6,327	3,270	$/kW
OpEx	39	39	39	$/kW/yr

- BOS component cost estimates are obtained from the LandBOSSE model (Eberle et al. 2019).
- Because CapEx data are scarce for distributed wind projects, further cost details on the individual system components are not presented.
- OpEx market data are not widely available for distributed wind projects; therefore, $39/kW/yr is assumed for each wind class and is aligned with the 2023 ATB atb.nrel.gov.

Source: NREL, ATB 2023

Wind Performance

Annual Average Wind Speed- m/sec

Kansas = **6.0 – 7.9** m/sec @ 60 meters

Florida = **3.0 – 4.9** m/sec @ 60 meters

1. **Altitude:** Wind speeds are higher at greater heights
2. **Time of day:** Day vs night hours
3. **Season:** Summer vs winter
4. **Local landscape:** Terrain; flat plains, hills, mountains, forests.
5. **Local weather:** Share of time the wind is blowing

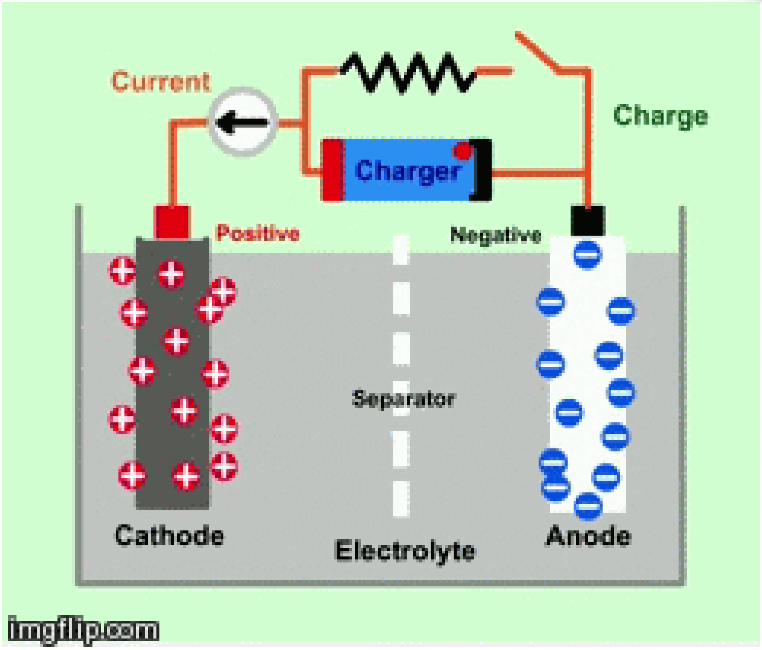
Source: NREL, 2018.

Battery Storage

Battery Electric Storage Systems or BESS

- Electrochemical
- Defined Power and Energy Capacity
- Rechargeable
- On-demand or as needed

Electricity IN



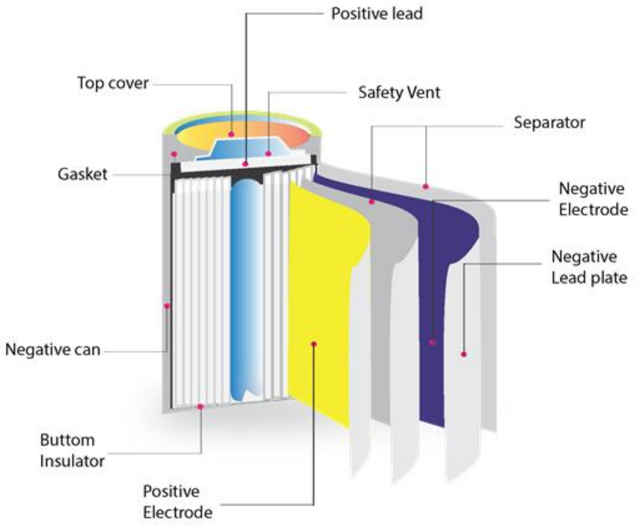
Electricity OUT

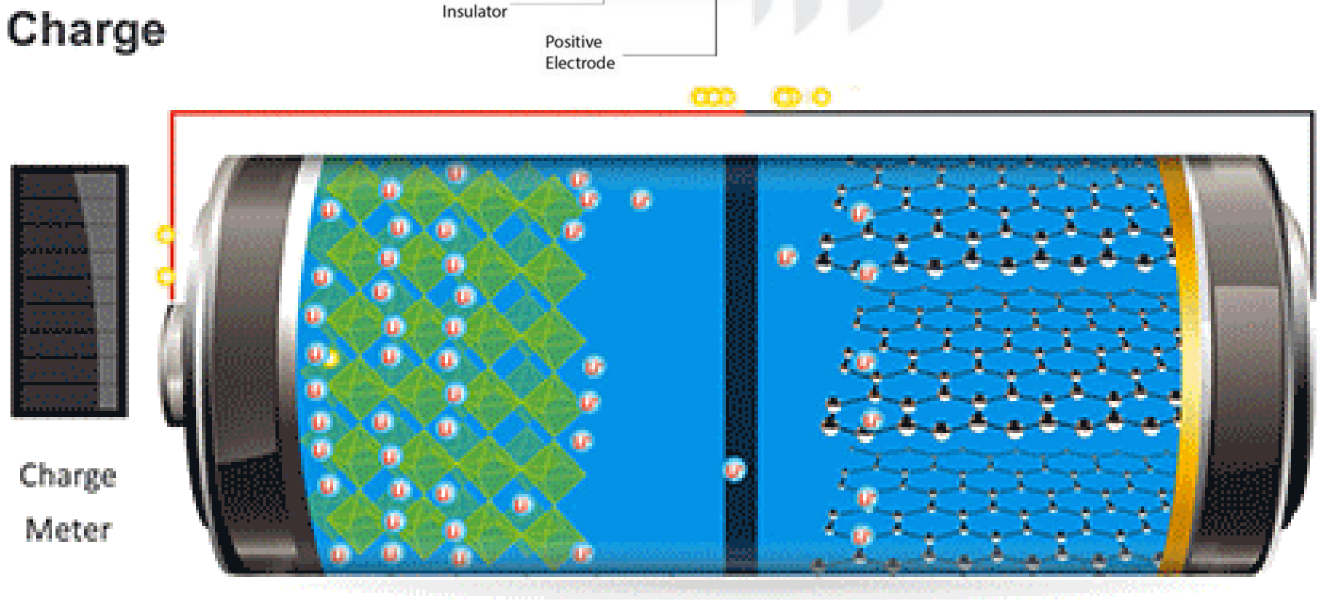
Chemical Energy
(Storage)

Source: https://gifer.com/en/LCEZ

Battery Electric Storage Systems or BESS

- Duration (hrs.)
- Degradation (1 - 3% /year)
- Depth of discharge (% DOD)
- State of charge (SOC)
- Cycle life
- End-of-life
- Round trip efficiency (RTE)
- Calendar life
- Second life

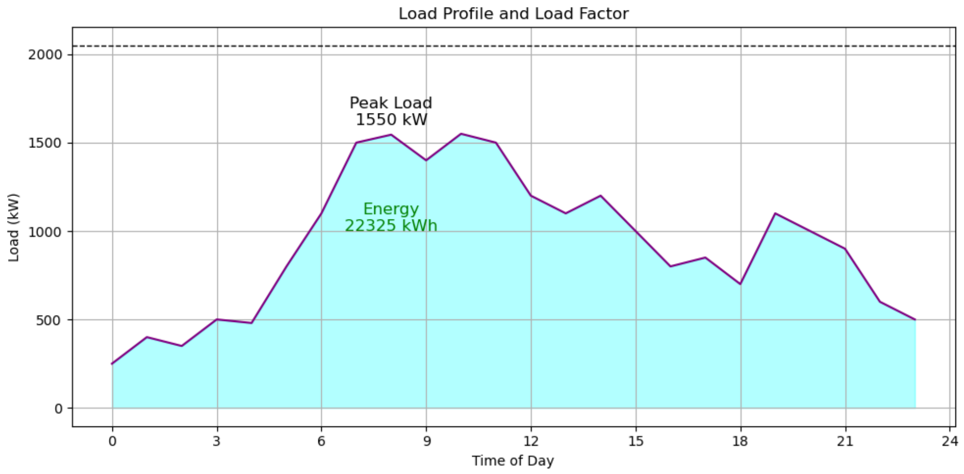




Source: DOE, Christine Holland (PNNL)

Load Factor (LF)

- Peak Load = Maximum Power Demand (kW or MW)



LF = Consumption / (Peak Load x Hours)
= 22325 kWh / (1550 kW x 24 hr)
= 0.60

$$LF = \frac{Average\ Load\ (kW\ or\ MW)}{Peak\ Load\ (kW\ or\ MW)}$$

- Average Load (kW or MW) = Total Consumption (kWh or MW) divided by the hours in period (hours)

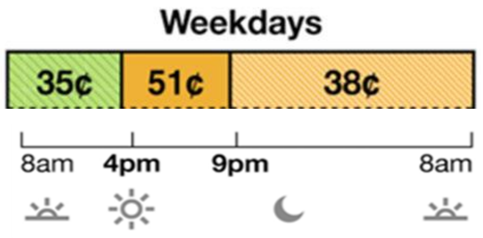
Facility Consumption Indicator

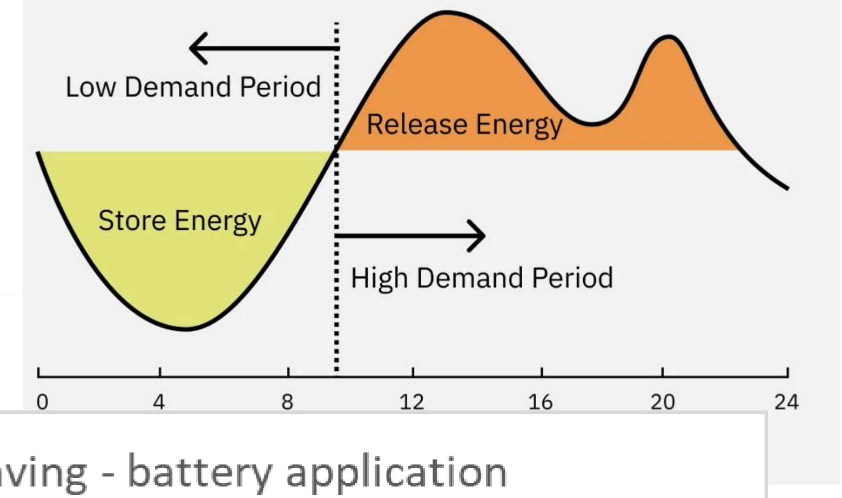
BESS Applications

- Energy Arbitrage
- Understanding billing structure
  - Demand Charges ($/kW)
  - Large differential between TOU rates
- Consumption Profiles
  - Assess facility Load Factor

Batteries alone cannot reduce overall consumption, only shift load => peak shaving and load flexibility

Example TOU Rates





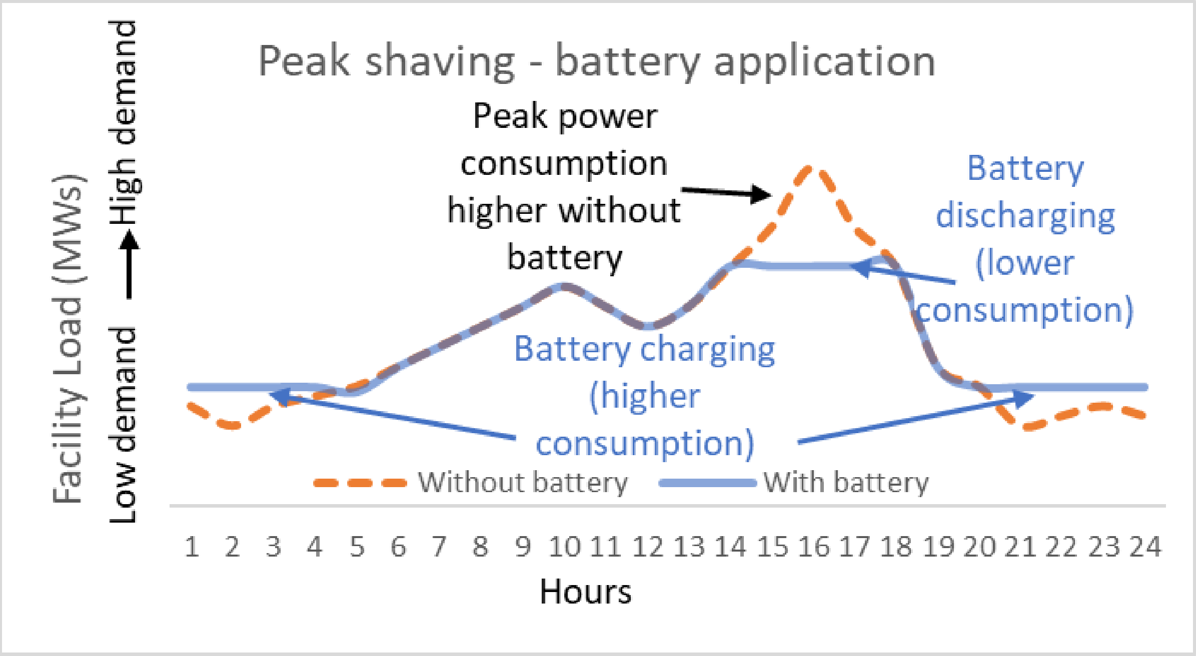
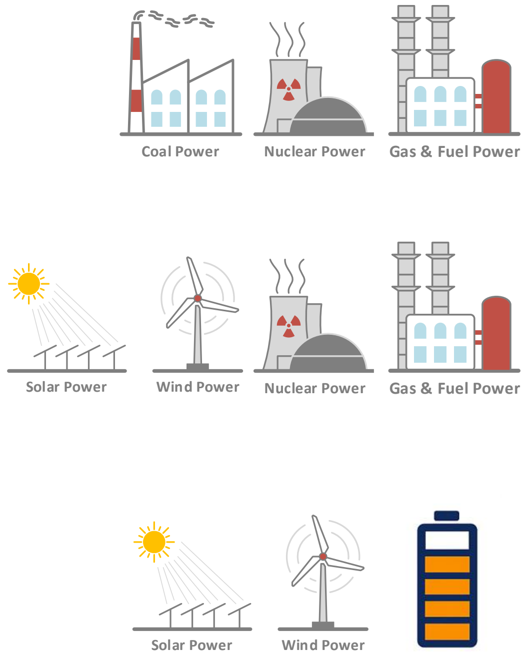


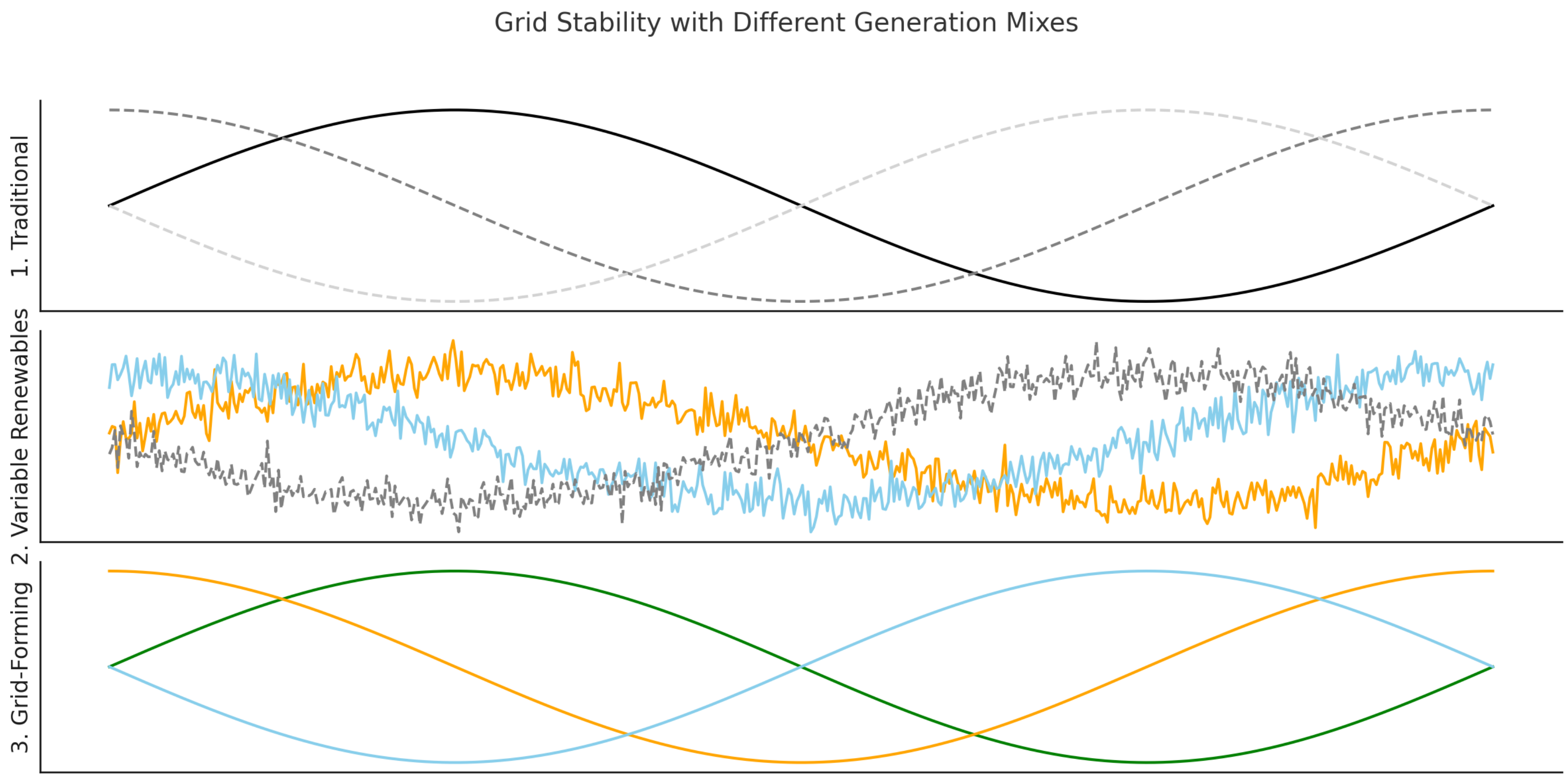
Image Source: Sabihuddin, S., et al. (2015) A Numerical and Graphical Review of Energy Storage Technologies. http://www.mdpi.com/1996-1073/8/1/172/htm

Adapted from: Christine Walker, PNNL

BESS Applications

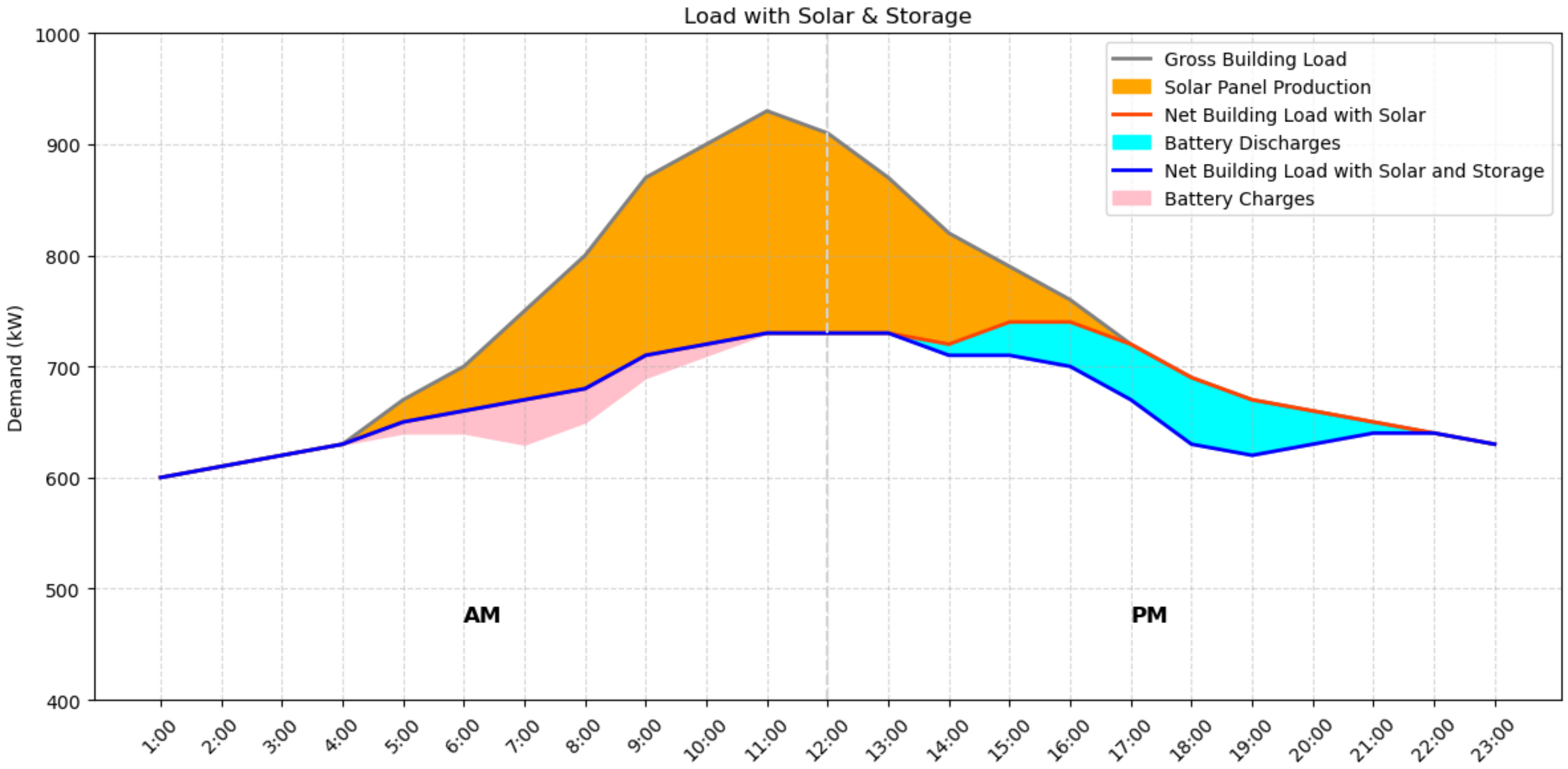
- Integrate Other Onsite Energy





BESS Applications

- Integrate Other Onsite Energy



Reduce marginal demand

Reduce marginal emissions

Smooth intraday variability

Reduce consumption using onsite sources

BESS Applications

- Emergency Generation
  - High instances of **outages**; extreme weather events
  - Provides **energy back-up** with and without renewable energy.
    - Size your system according to desired length of outage and to the capacity factor of the supply origin (i.e., solar, CHP)

- Power Quality Improvements
  - Mitigation of power fluctuations by providing **voltage regulation**.
    - Nearly instantaneously inject or absorb electricity from or into the grid to stabilize voltage irregularities.
  - **Frequency regulation** by adjusting charging and discharging rates, ensuring a consistent power supply.
  - **Black start capability** by providing immediate power ensuring faster system stabilization.
  - May be able to provide grid services (such as **ancillary services**) in partnership with utilities

Battery Electric Storage Types

Characteristic	Lithium-ion	Flow	Thermal (high temperature)
Energy Storage Conduit	Energy is stored in electrode material with 6 different cathode materials: iron phosphate (LFP), cobalt oxide, manganese oxide, nickel manganese (NMC) cobalt oxide, titanate, and nickel cobalt aluminum oxide; with LFP and NMC being most common	Electrolytes flow through one or more electrochemical cells from one or more tanks. Three battery types: conventional, hybrid, and membrane-less, with the two most common being vanadium redox and zinc-bromide hybrid	Molten salt - typically use a sodium-sulfur compound, operating at temperatures around 300 – 700° Celsius, releasing stored energy as either heat or electricity. Designed for rapid use and extreme temperatures (e.g., well suited to the aerospace industry)
Development Stage	Widely commercialized	Early commercialization	Early commercialization
Lifespan (# of cycles)	Depends upon cycling – if cycled everyday may only last 8 years. (1,000-2,500) Calendar life ≈16 years	Unlimited battery cycle life – can be cycled everyday up to 30 years. (12,000-14,000)	Approximately 20 years (approximately 10,000)
Duration	Most common is 4 hours	Commonly up to 10 hours	10-15 minutes
Cost ($/kWh)	$360 - $575	$356 - $836	$69 - $155
Storage Efficiency	86%	90-95%	75-99%

Battery Electric Storage System Components

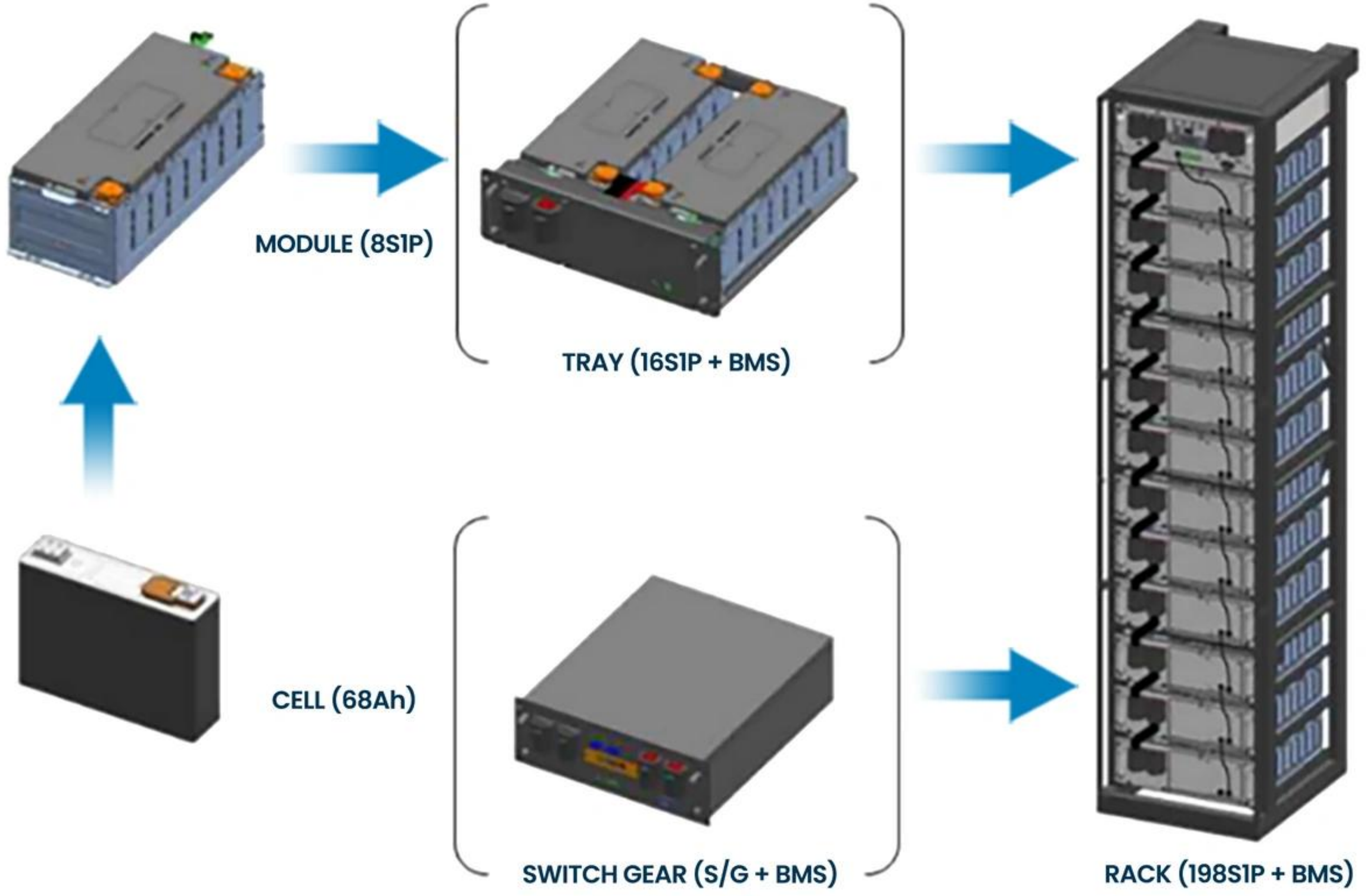
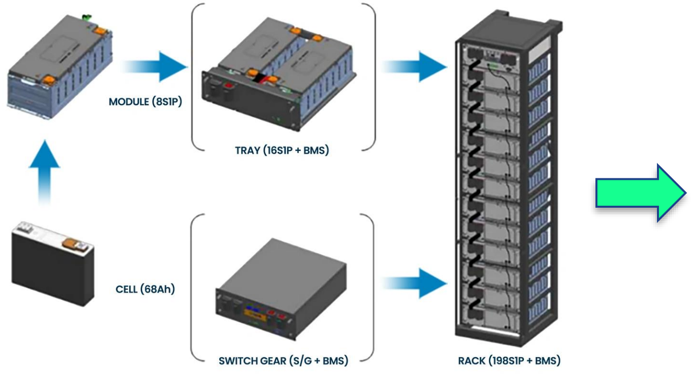
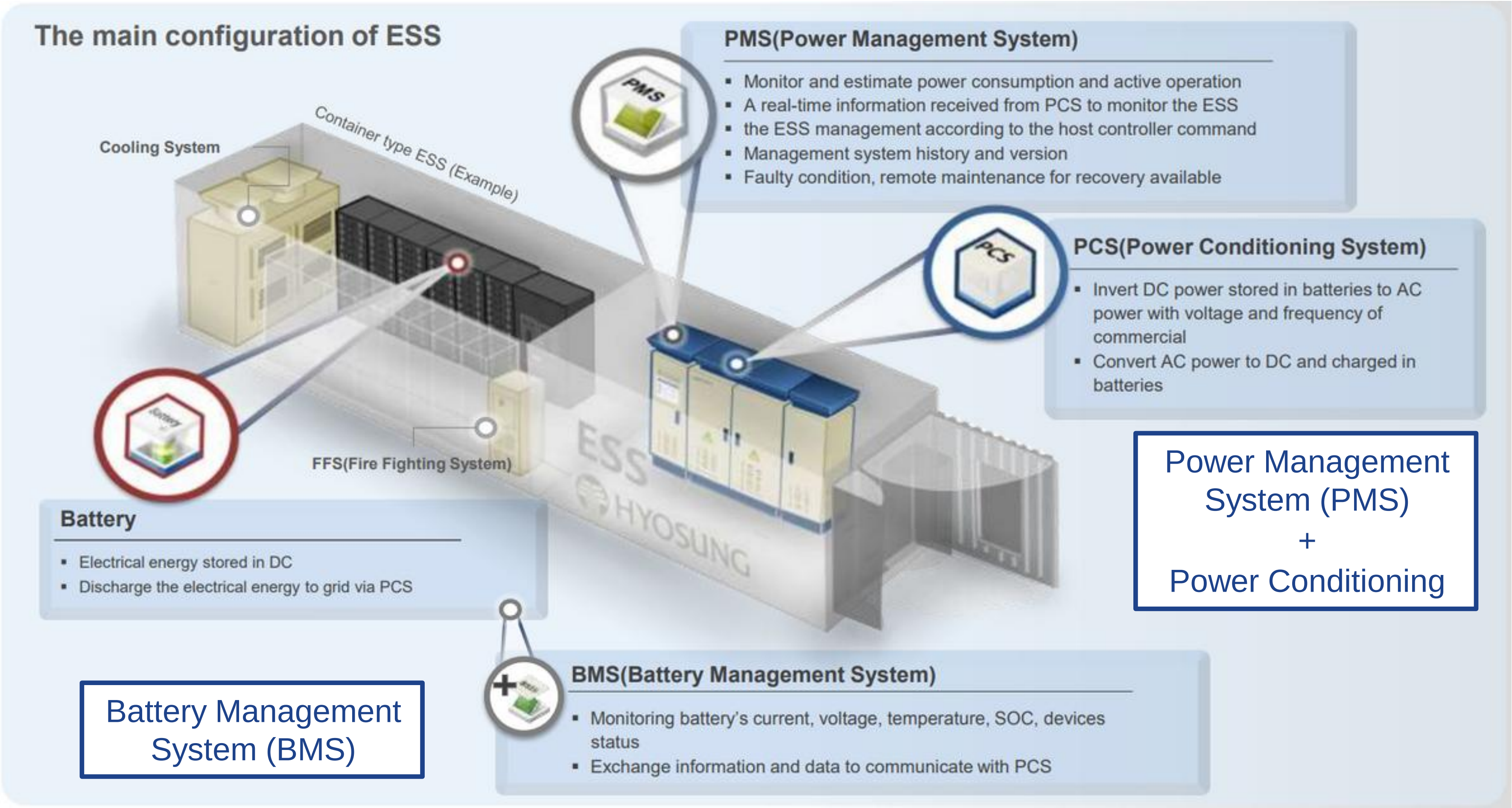


Image Source: Energy Toolbase

Battery Electric Storage System Components





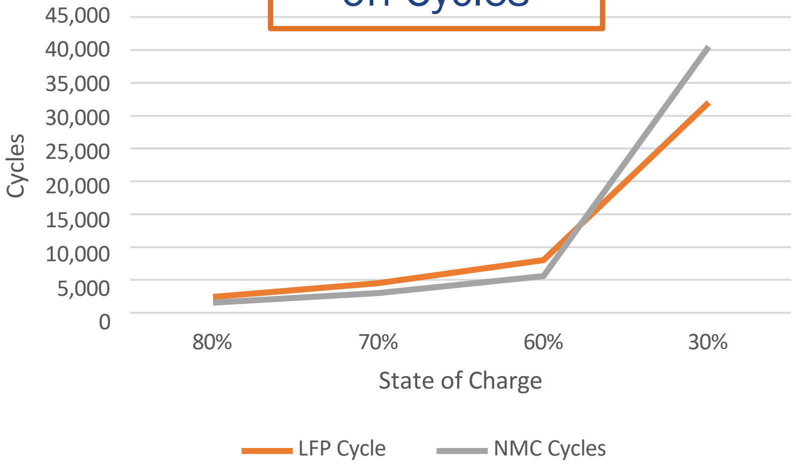
Power Management System (PMS)
+
Power Conditioning

Battery Management System (BMS)

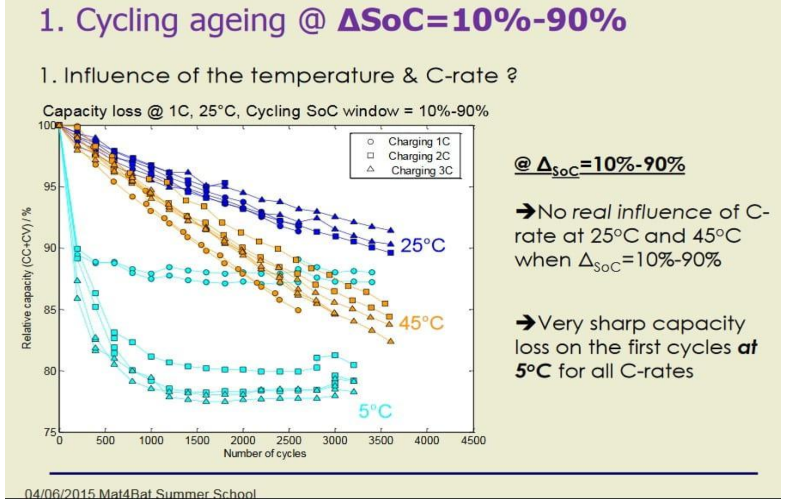
Performance Parameters

Li +	2021 technology	2030 technology
RTE (%)	83%	85%
Cycle Life (number)	2400	2640
Calendar Life (yrs)	16	16
DOD (%)	80%	80%

SOC Impact on Cycles



Temperature Impact on Cycles



Discharge Rate

Higher discharge rates

⇩

Greater chemical reactions

⇩

More heat expended and energy lost

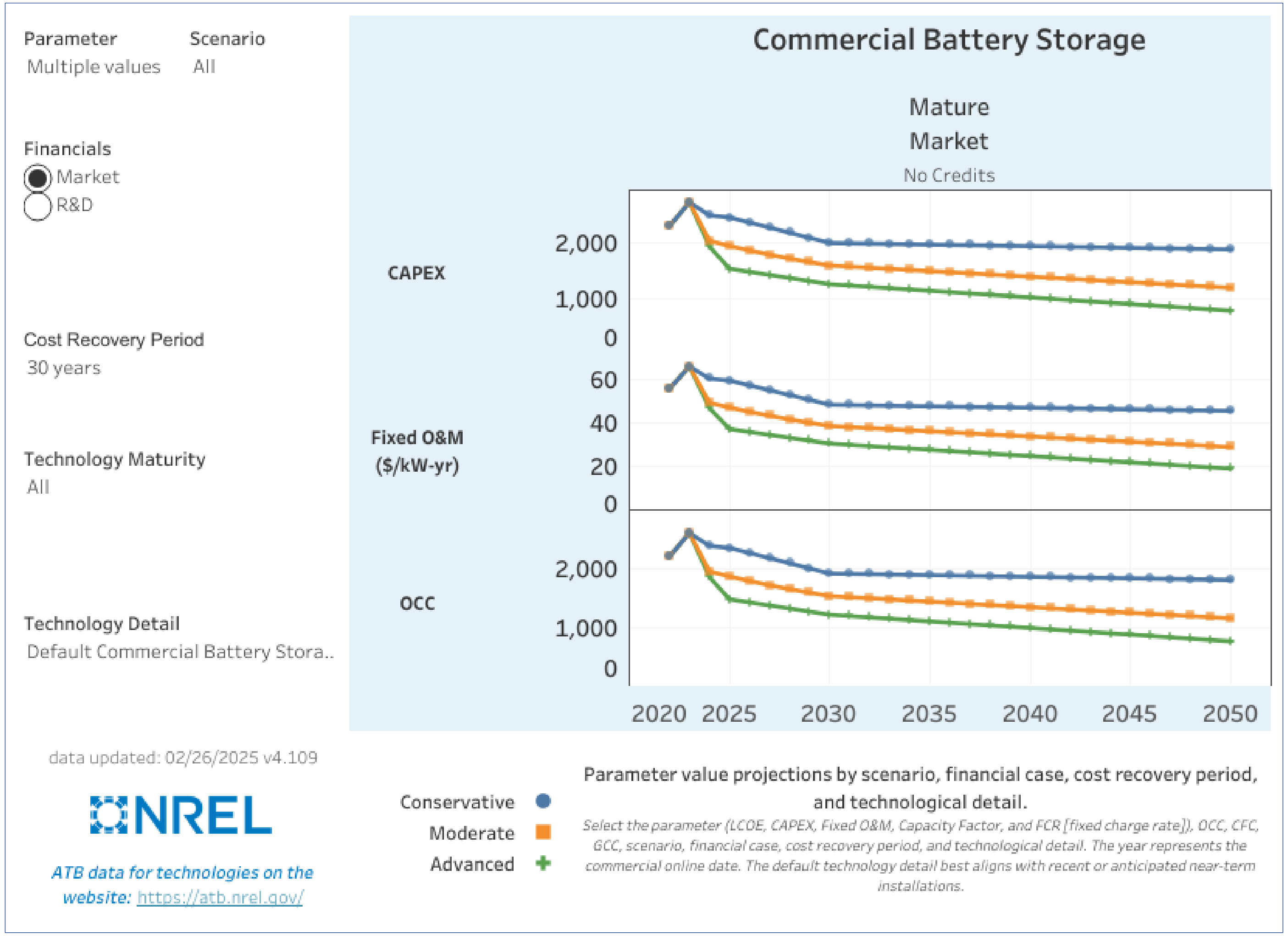
Adapted from: Christine Walker, PNNL

Source: [2022 Grid Energy Storage Technology Cost and Performance Assessment]

Lithium-ion Battery Cost For Commercial Applications

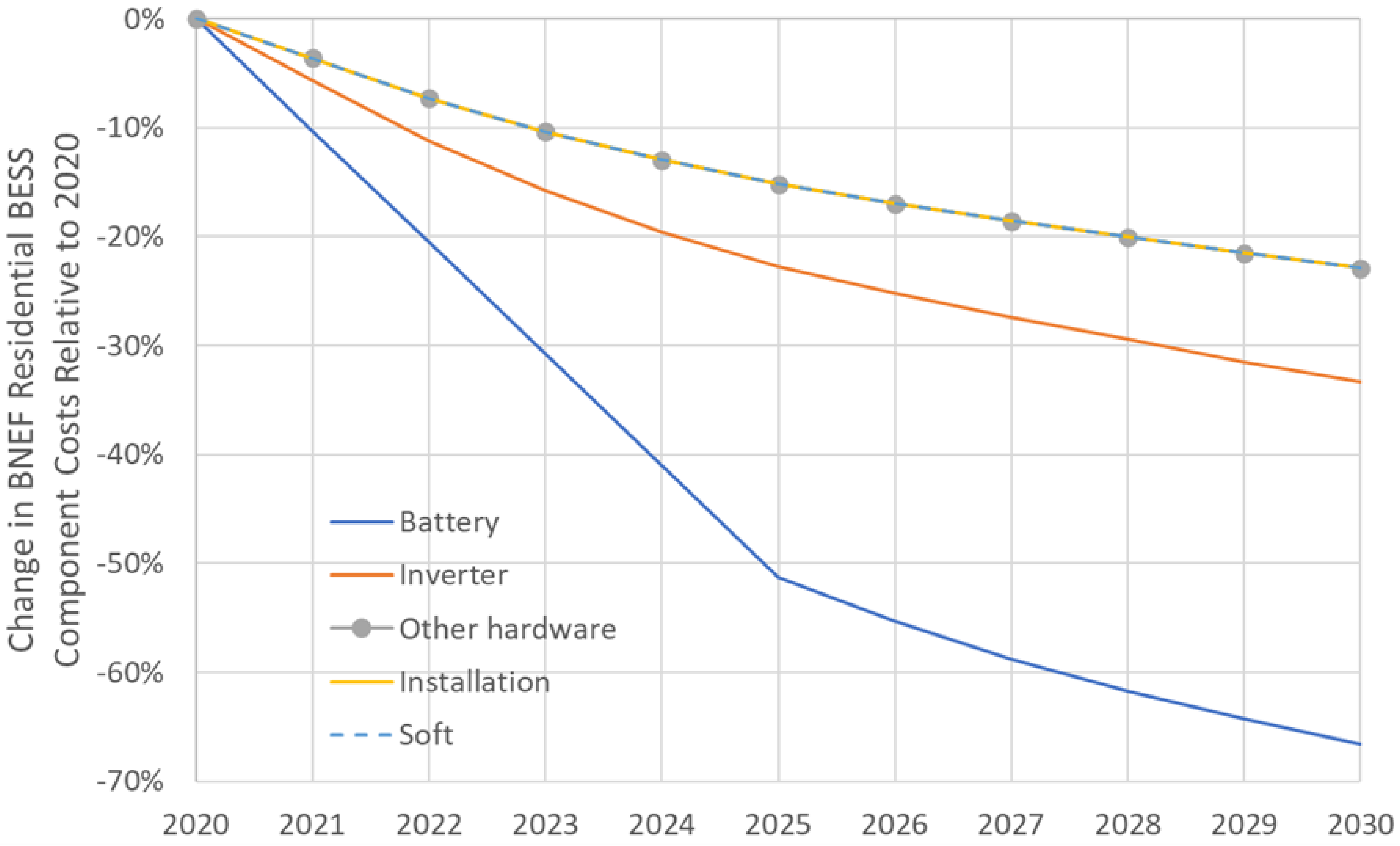
- Opportunity for utility partnership/creative financing
  - BESS is expensive, but broader cost considerations make them more attractive

- Capital costs are forecasted to decrease
  - Based on NREL's Annual Technology Baseline forecast costs are expected to decline by 16% through 2030 (most conservative case).



Lithium-ion Battery Cost For Commercial Applications

$$Total\ System\ Costs\ (\$/kW) = \frac{\left(Battery\ Pack\ Cost\ \left(\frac{\$}{kWh}\right) * Battery\ Energy\ Capacity\ (kWh)\right) + \left(Battery\ Power\ Capcaity\ (kW) * BOS\ Cost\ \left(\frac{\$}{kW}\right)\right) + Battery\ Power\ Constant\ (\$)}{Battery\ Power\ Capacity\ (kW)}$$



Rule of Thumb: $400/kWh plus operation costs

Formula: Cole and Karmakar (Cole and Karmakar, 2023)

Data: BNEF. "Energy Storage System Costs Survey 2019." BloombergNEF, October 14, 2019

Wrapping Up!

Partners Case Studies

Volvo's powertrain facility at Hagerstown, MD:

I. July 2015 – Solar canopy for the entire plant's parking lot with 5,000 solar panels (1.3 MW capacity).
II. May 2016 – Ground mount solar PV panels, 2,094 kW capacity, covers 50% of the plant's electricity via PPA.

VOLVO
VOLVO GROUP

Solar canopy in the parking lot

Ground mounted solar PV system

Sources: https://www.volvogroup.com/en/news-and-media/news/2015/sep/volvo-groups-hagerstown-site-installs-solar-canopy.html
https://www.newenergyequity.com/project/volvo-trucks-usa/

Partners Case Studies

The Estée Lauder Companies …

In 2020, The Estée Lauder Companies added 3.8 MW of solar power at the corporation level to bring the global company's total to more than 5 MW of solar capacity. In the United States, a 1.45 MW ground-mounted solar array was installed in their Melville, New York site. This project is expected to produce more than 1,800 MWh/year of solar power and reduce 1,300 MT of CO_2 emissions annually. Also, at the Blaine, Minnesota facility, around mid-2020, the installation of 900-kW (3.6-acre) solar PV array was completed to supply 50% of the manufacturing facility's annual demand.

ESTĒE LAUDER COMPANIES

"3.8 MW of solar power was added in 2020"

Melville, New York

Blaine, Minnesota

CalPortland … Cement Plant

CalPortland signed a PPA for 24 MW wind turbine generation facility that consists of eight 3 MW wind turbines—as part of the Alta Wind Energy Center—to directly supply electricity to its Mojave cement plant. The 24 MW wind farm generates around 40,000 MWh annually, which covers 20% of the plant electricity consumption.

"24 MW wind turbine generation facility, 40,000 MWh/year"

CALPORTLAND®

Part of the Alta Wind Energy Center near CalPortland's cement plant in Mojave, CA

Source: https://www.elcompanies.com/en/our-commitments/sustainability/climate-and-environment

Source: https://www.calportland.com/calportland-signs-new-ok-raw-mill-deal-with-flsmidth/

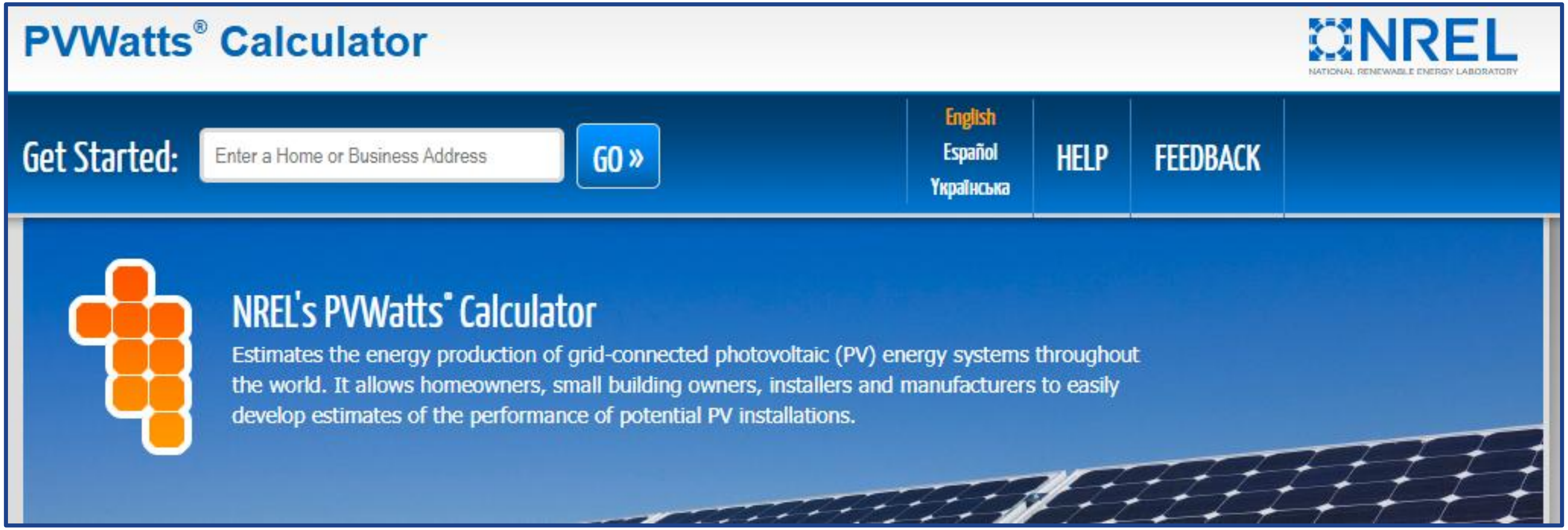
Other Resources:

- Onsite Energy Program
- Better Plants Solutions Center
- Federal Battery Storage Tax Credit
- State-Level Incentives
- General Energy Storage Facts
- U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks
- Energy Storage Cost and Performance Database
- DOE Factsheets on Energy Storage
- DOE Factsheets on Distributed Wind Power
- DOE Factsheets Solar Photovoltaic Panels For Industrial Applications
- Grid-scale Energy Storage Technologies Primer – NREL
- 2024 Electricity ATB Technologies and Data Overview

PVWatts Demo

PVWatts Calculator

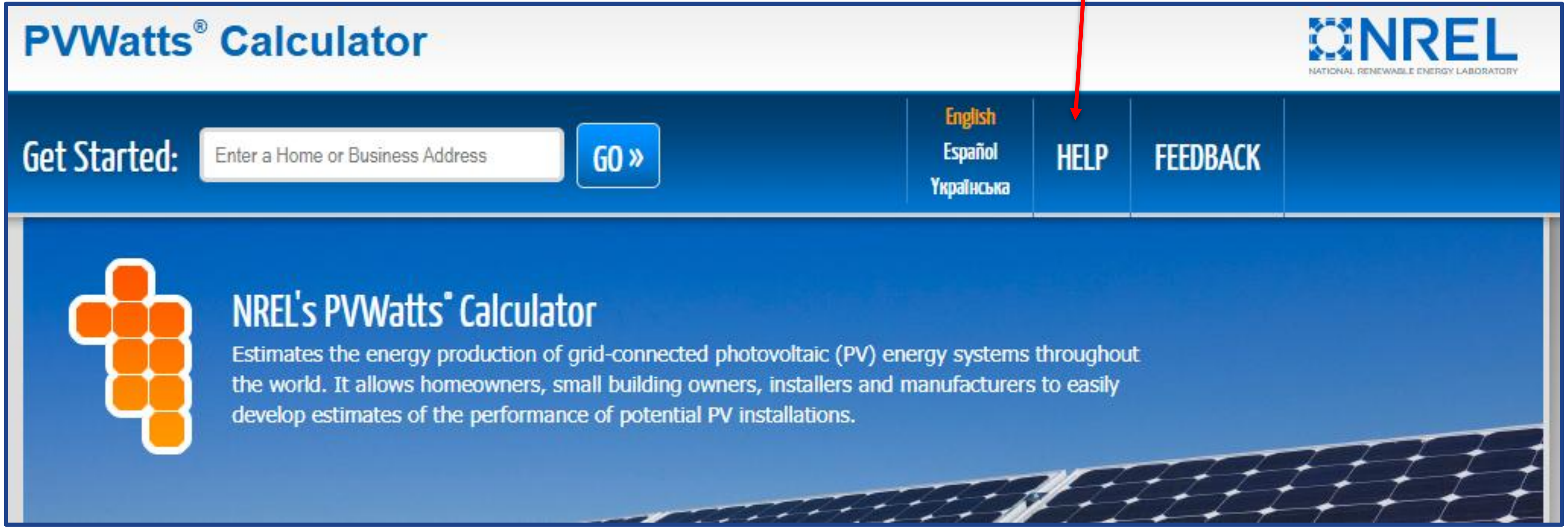
- Go to https://pvwatts.nrel.gov/



PVWatts Calculator

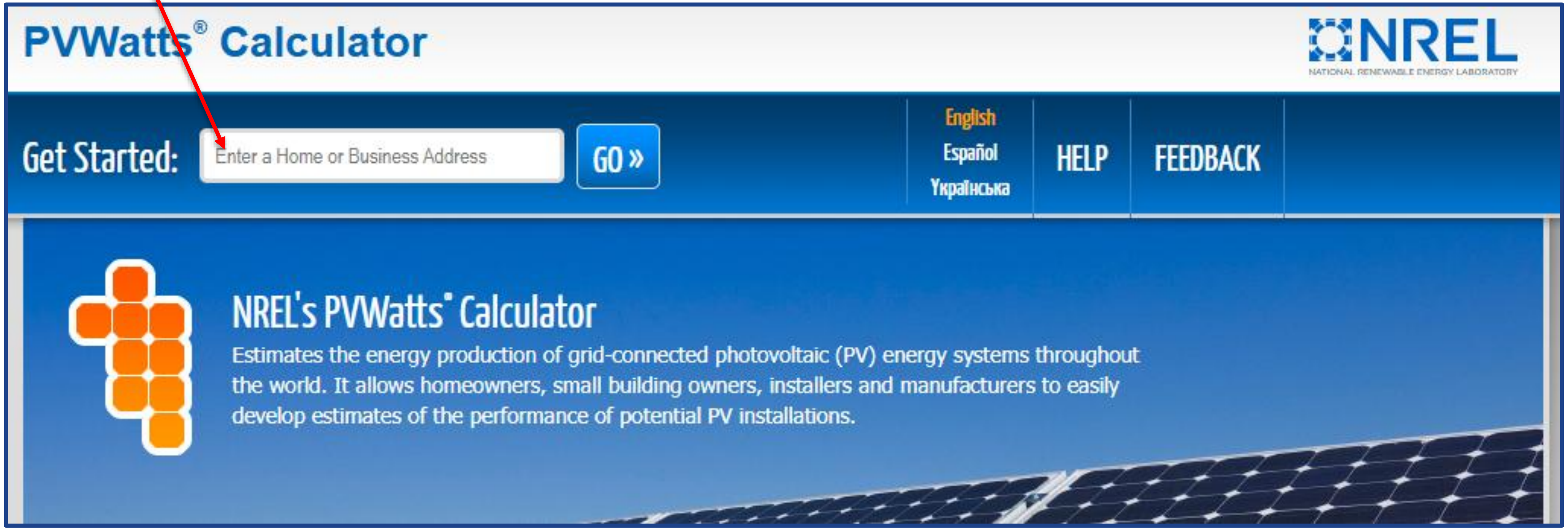
- Go to https://pvwatts.nrel.gov/

Help and Documentation



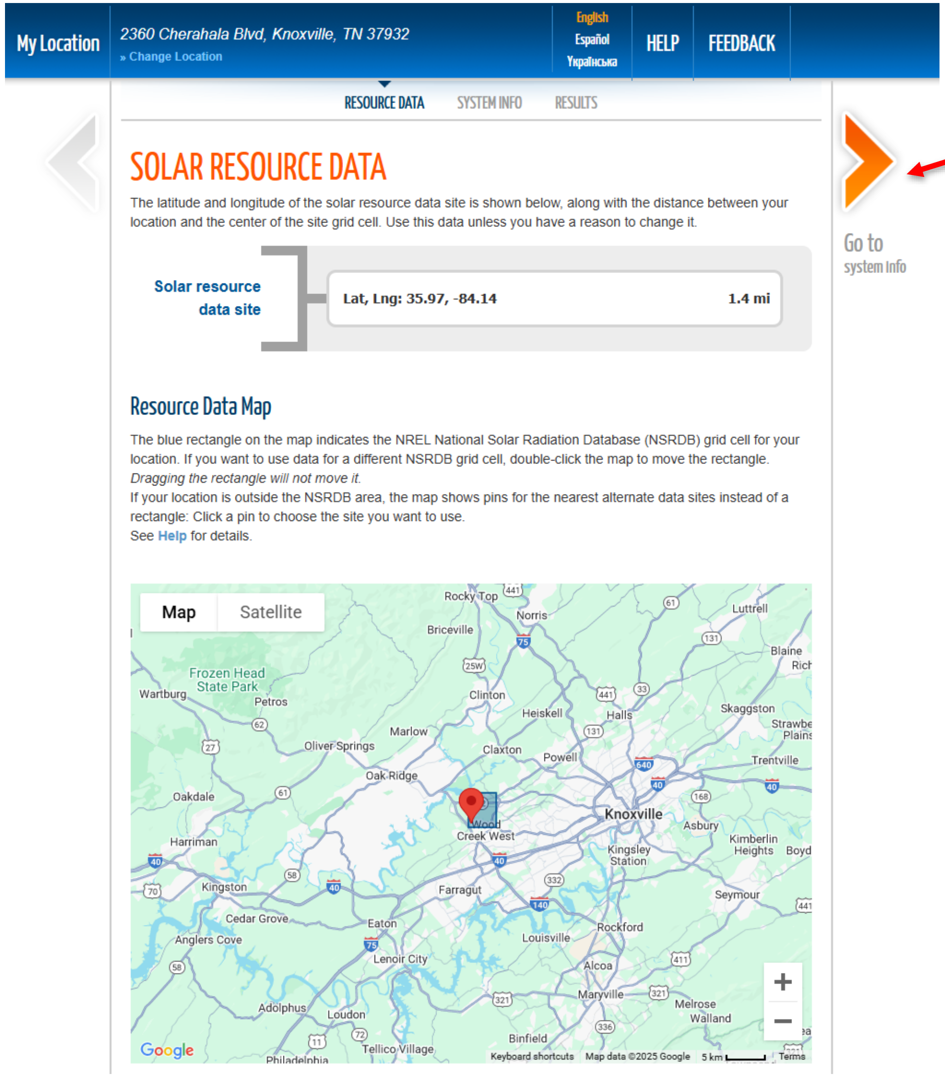
PVWatts Calculator

1. Enter facility address here

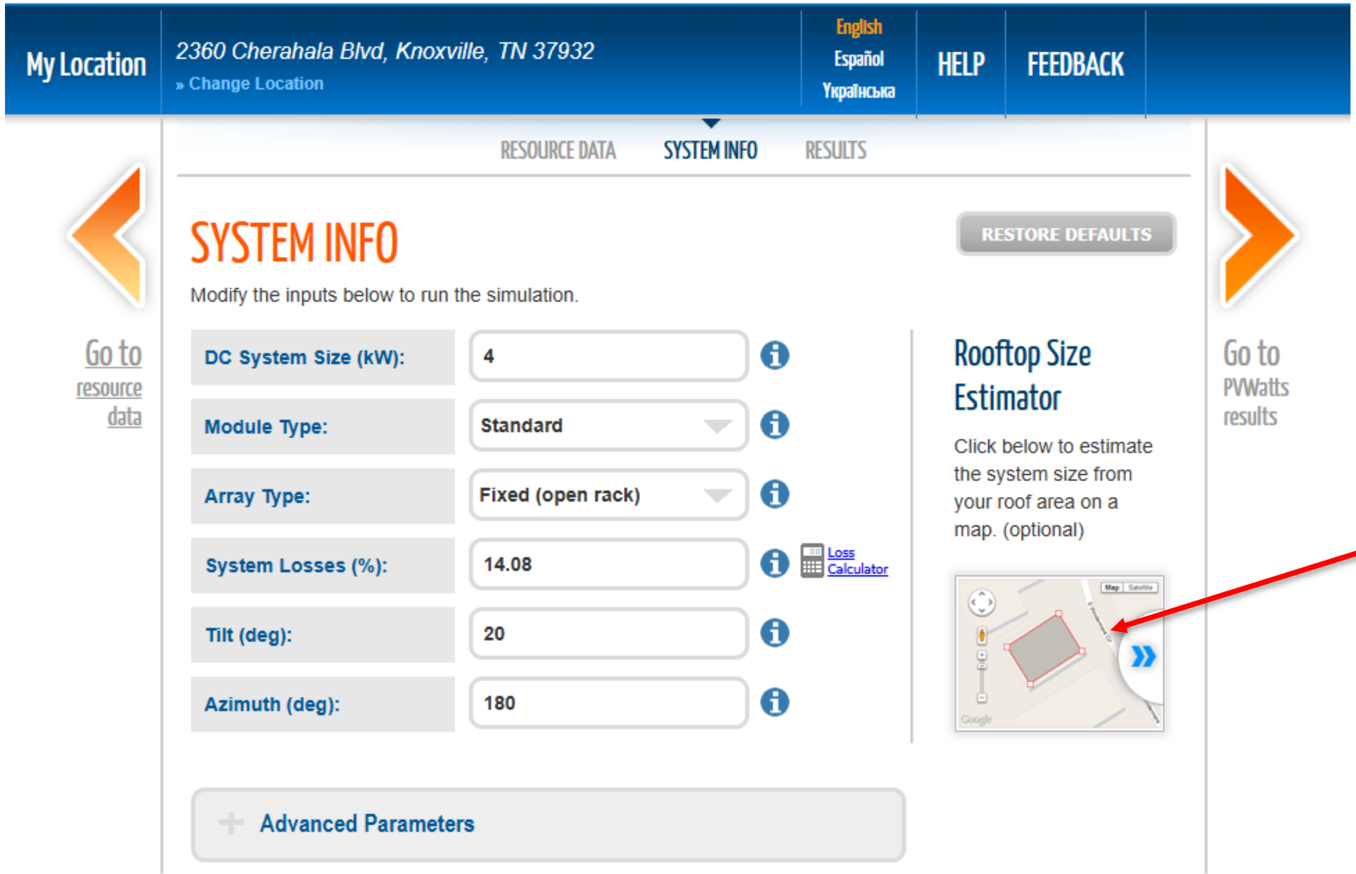


PVWatts Calculator

2. After verifying information, click “system Info”

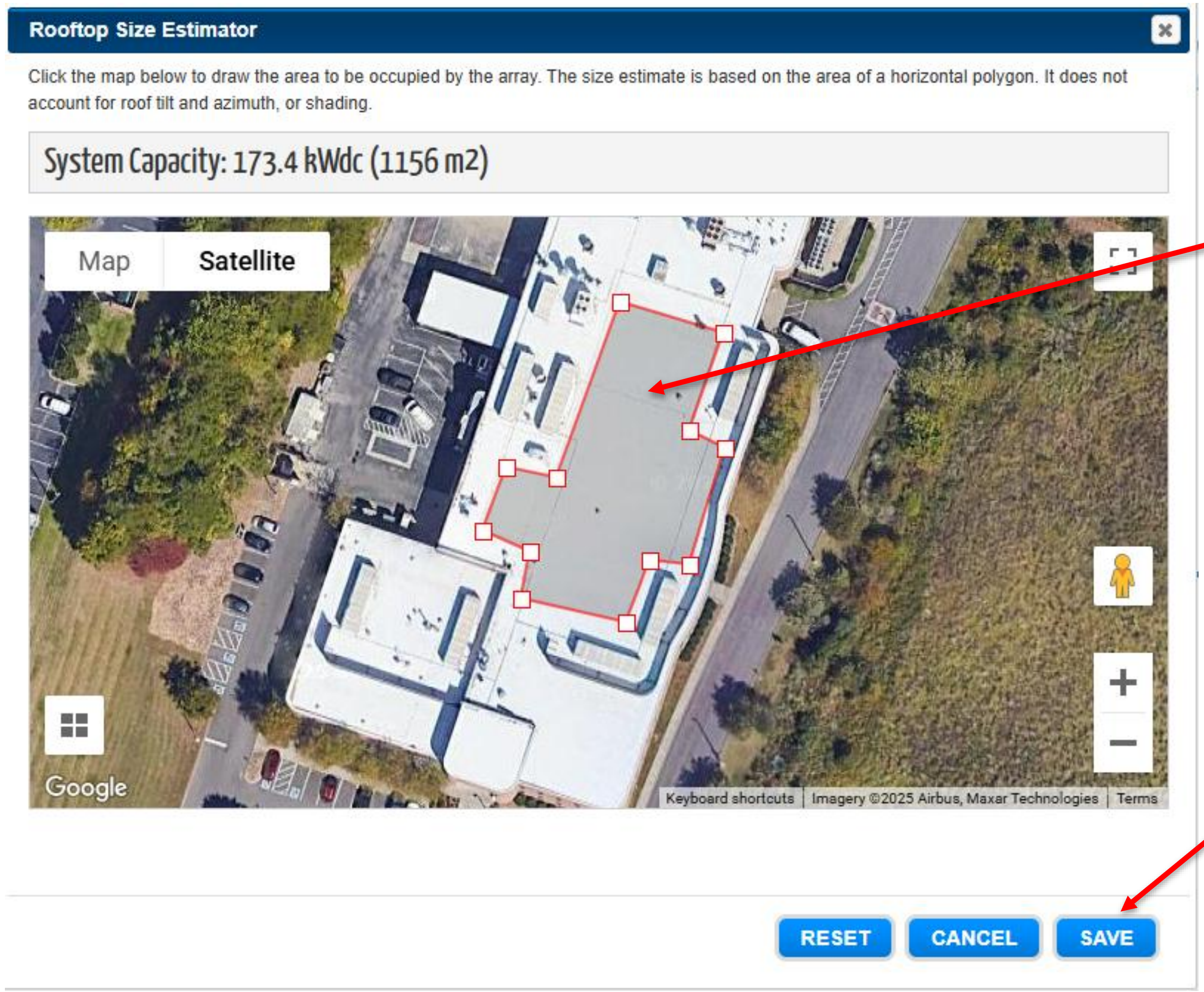


PVWatts Calculator



3. Adjust roof size

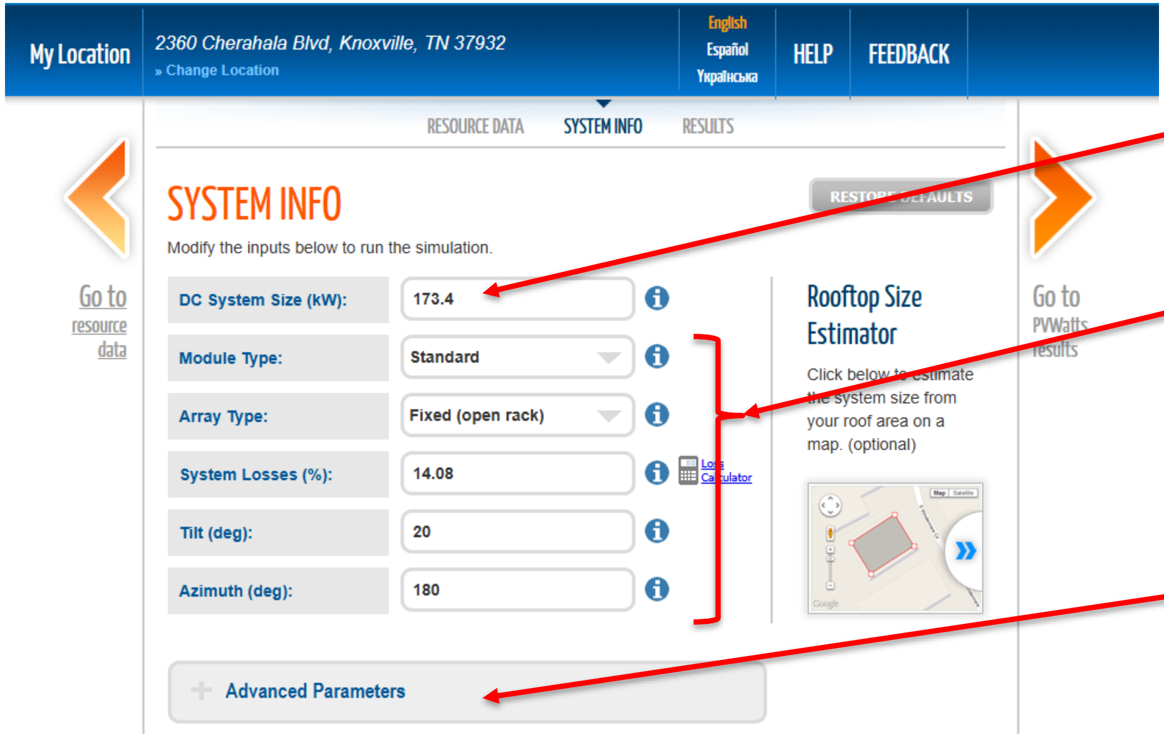
PVWatts Calculator



3. Draw system design

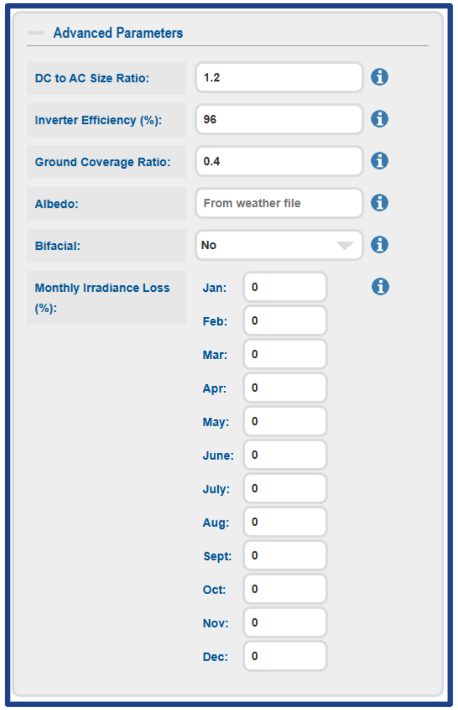
4. Click "Save"

PVWatts Calculator



5. Review system capacity

6. System details



7. Advanced Parameters cover additional information for specific systems and equipment selection

PVWatts Calculator

RESULTS

Print Results

234,210 kWh/Year*

System output may range from 230,088 to 248,075 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	3.54	15,457
February	3.84	14,807
March	4.74	19,524
April	5.70	21,937
May	6.13	24,054
June	6.27	23,254
July	6.14	23,444
August	6.03	22,984
September	5.61	21,006
October	4.90	19,557
November	3.66	14,873
December	3.05	13,313
Annual	**4.97**	**234,210**

User Comments

Type here to add optional comments to printout.

Download Results: Monthly | Hourly

Find A Local Installer

8. Download results

* **Caution:** The PVWatts energy estimate is based on an hourly performance simulation using a typical-year weather file that represents a multi-year historical period for Knoxville, TN for a Fixed (open rack) photovoltaic system. The kWh range is based on analysis of a nearby data site described here.

These results are based on assumptions described in Help that may not accurately represent technical characteristics of the project you are modeling.

Questions?

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Download SAM

https://sam.nrel.gov/

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Homework #2: Due COB Monday 6/16

Please use the link below to access the *PV Watts Tool* tool to estimate the energy production of grid-connected photovoltaic (PV) energy system for your facility.

- **Data needed** before running the simulation:

  1- Address of facility or intended location

  Example: 2350 Cherahala Blvd, Knoxville, TN 37932

Please write below your location and estimated system size:

Address: ____________

Select Area: Using mouse

System Capacity: ___**kW**

https://pvwatts.nrel.gov

Thank you!