Solar & Wind

Tribal Energy Webinar Series

Tony Jimenez, Senior Engineer
NREL

May 27, 2020

Presentation Overview

Technologies

- Solar (PV) Technology
- Wind Technology
- Project Types (contractual)

For solar and wind technology, this presentation examines:

- Resource (description, extent)
- Technology (how it works)
- Market status (deployment and cost trends)

Solar Energy

NREL Image Library # 08058

Resource: Definitions & Components

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Irradiance (power/area): Incoming solar power flux. Typical value of irradiance at midday in the summer 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 ~ 4.5 kWh/m^2. The unit kWh/m^2 is sometime called a "sun-hour".

Direct Normal Irradiance (DNI): the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. Typically, you can maximize the amount of irradiance annually received by a surface by keeping it normal to incoming radiation. This quantity is of particular interest to concentrating solar thermal installations and installations that track the position of the sun.

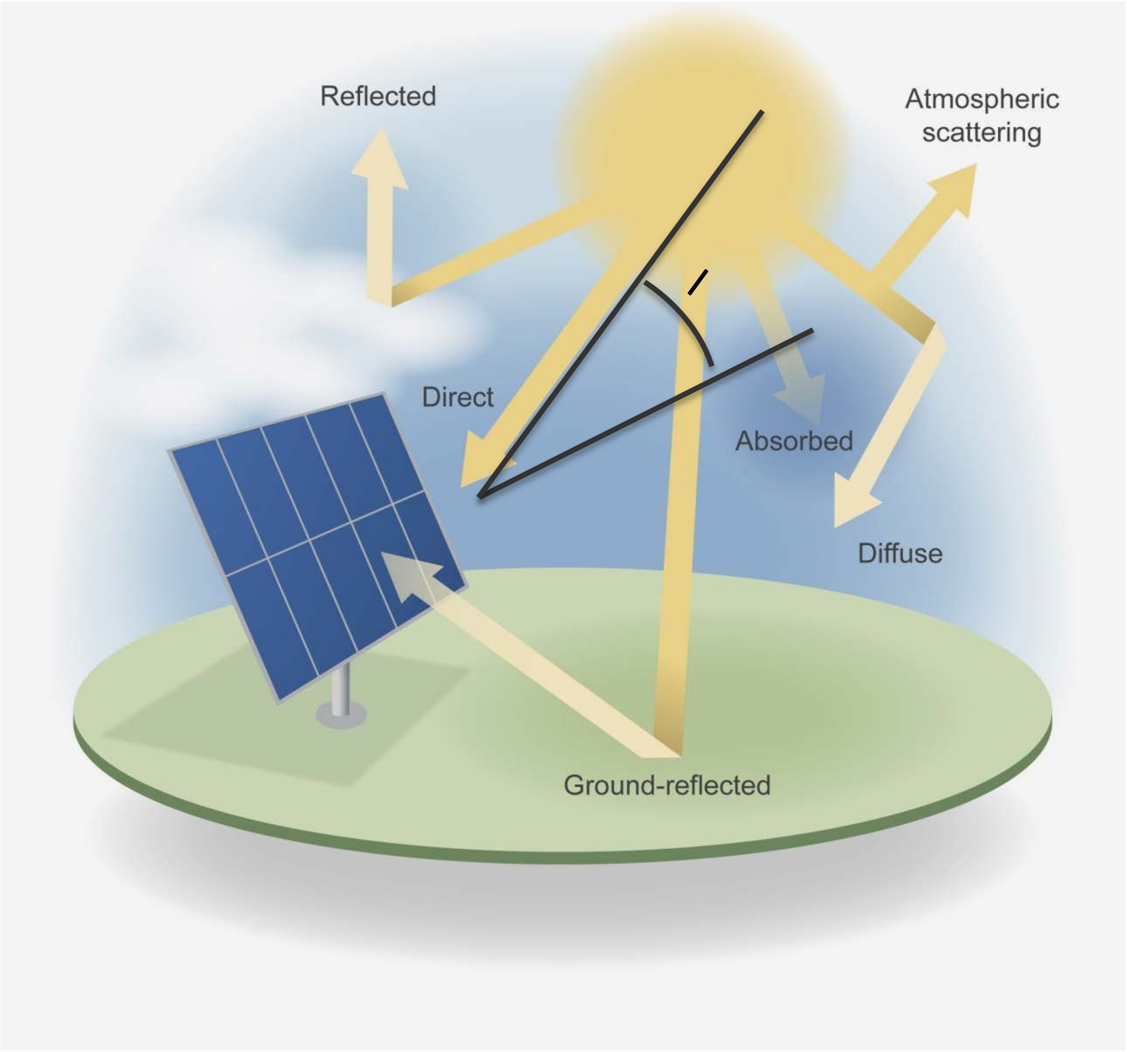
Diffuse Horizontal Irradiance (DHI): the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun but has been scattered by molecules and particles in the atmosphere and comes equally from all directions.

Global Horizontal Irradiance (GHI): the total amount of radiation received from above by a horizontal surface. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI).

Reflected Irradiance: the amount of radiation received per unit area by a surface that has been reflected (typically) from the ground.

Resource: Irradiance Components

SOLAR



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

I = Solar Incidence Angle

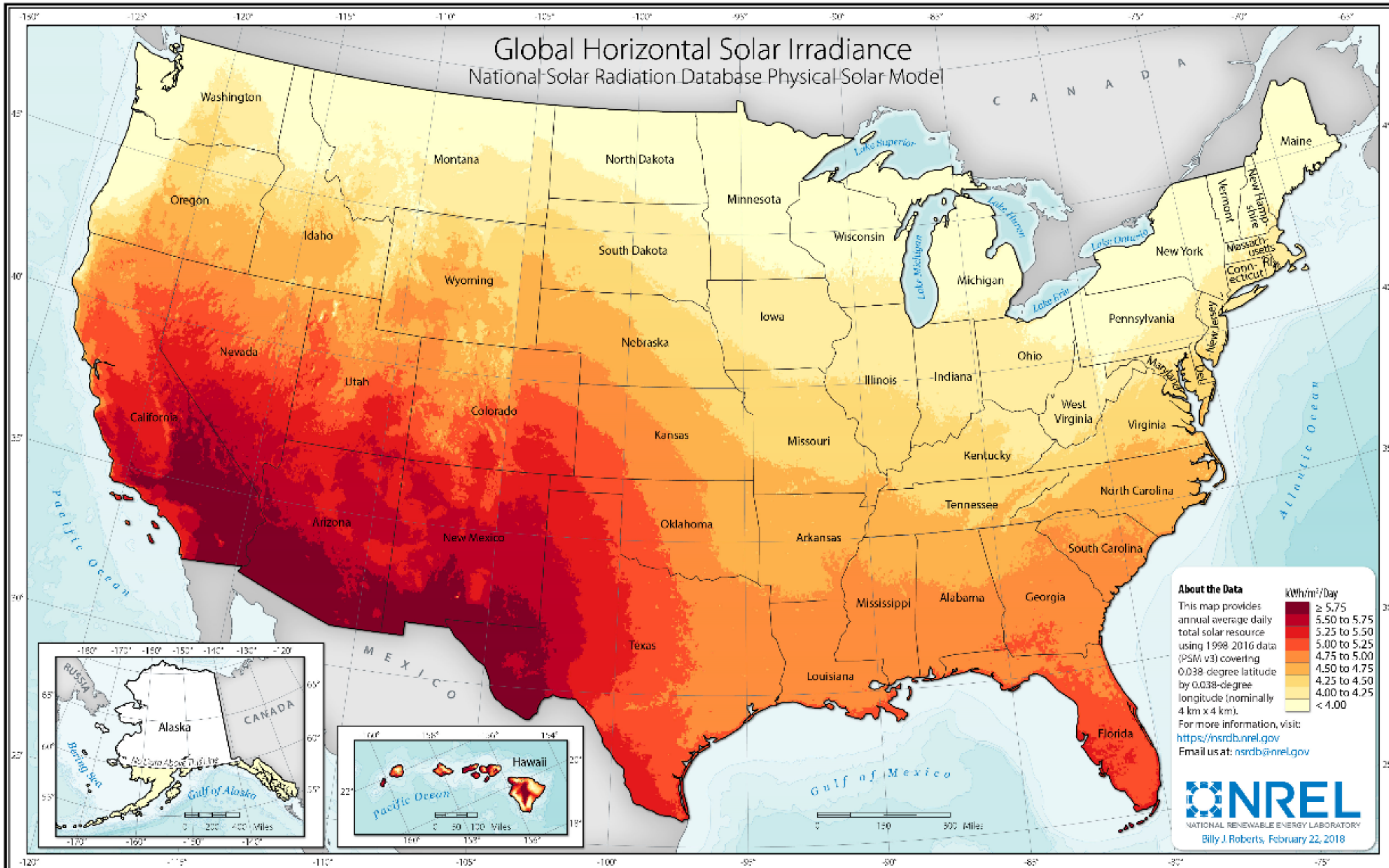
Direct Normal "Beam"

Diffuse "Sky"

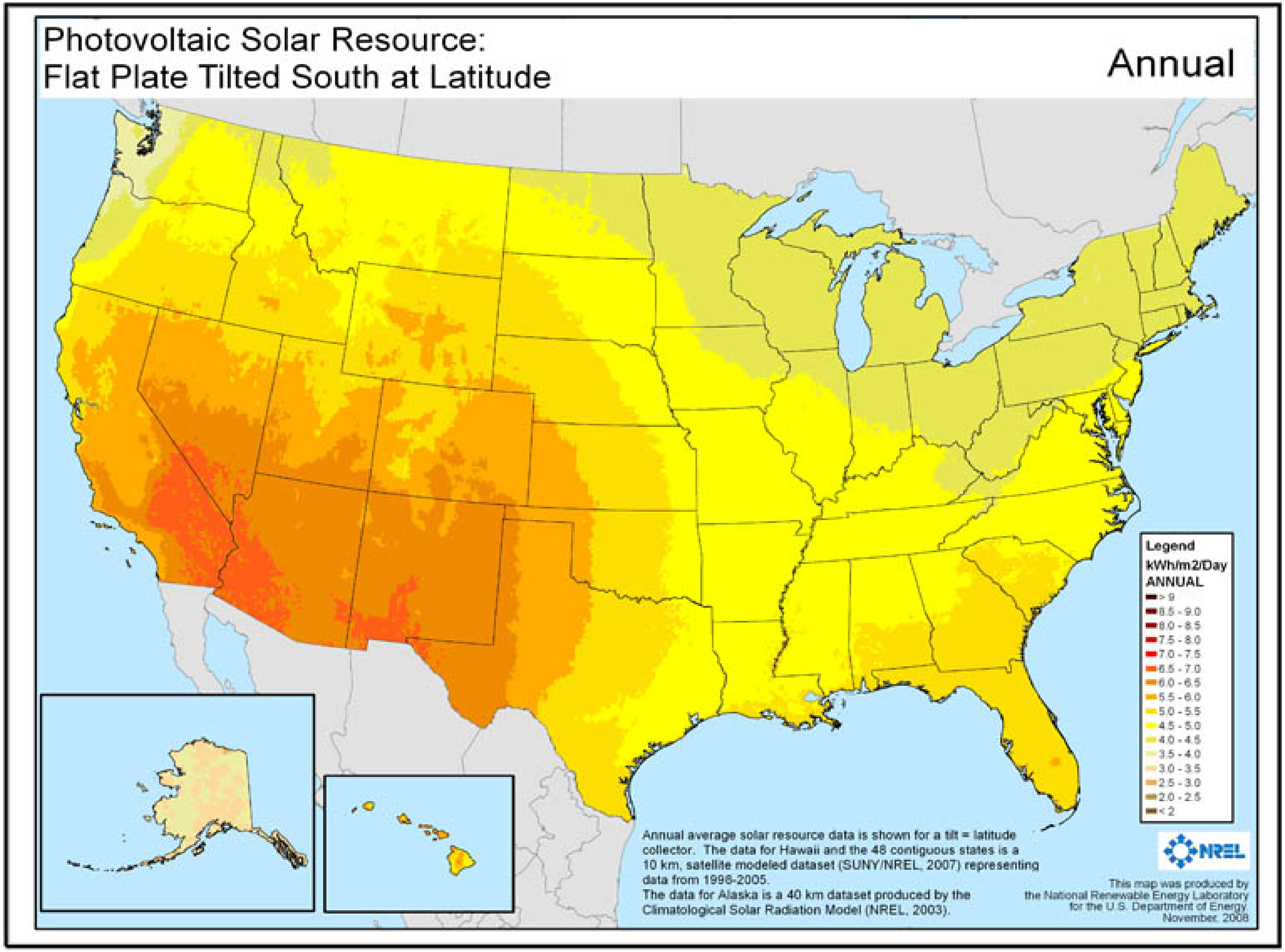
Total Hemispheric on *Horizontal* Surface "**Global**"

SOLAR

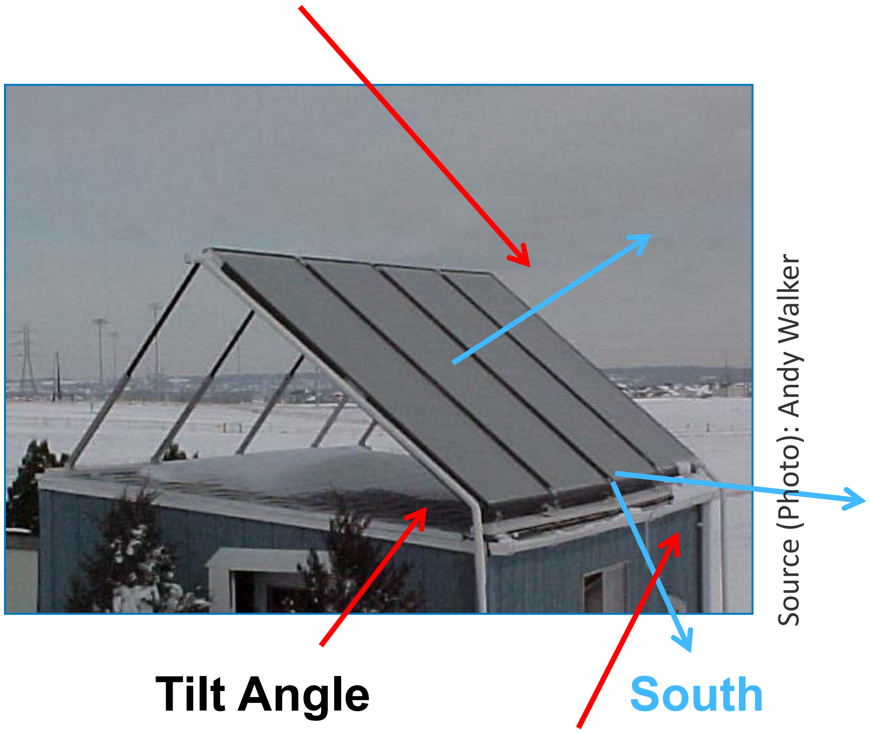
Resource: Horizontal Surface



Resource: Surface Tilted at Latitude



Resource: Panel Orientation



Normal: The vector that projects perpendicular from the plane surface

Tilt: Angle between the panel surface and the ground.

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

Angle of Incidence: Angle between the beam radiation on a surface and the normal to that surface

Zenith Angle: Angle between the sun and a vertical line (sun directly up in the sky = zenith angle of zero)

SOLAR

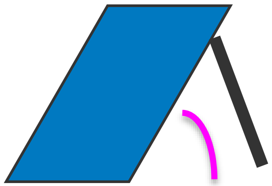
Solar Resource: Effect of Tilt & Azimuth

Analysis for Atlanta, GE. 34 Degree North

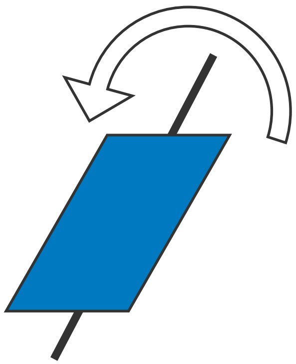
Azimuth - Compass Bearing

Array Tilt (Degrees)		270° (West)	255°	240°	225° (SW)	210°	195°	180° (South)	165°	150°	135° (SE)	120°	105°	90° (East)
Vertical	90°	56	60	64	67	69	71	71	71	71	69	65	62	58
	80°	63	68	72	75	77	79	80	80	79	77	74	69	65
	70°	69	74	78	82	85	86	87	87	86	84	80	76	70
	60°	74	79	84	87	90	91	93	93	92	89	86	81	76
	50°	78	84	88	92	95	96	97	97	96	93	89	85	80
	40°	82	86	90	95	97	99	100	99	98	96	92	88	84
	30°	86	89	93	96	98	99	100	100	98	96	94	90	86
	20°	87	90	93	96	97	98	98	98	97	96	94	91	88
	10°	89	91	92	94	95	95	96	95	95	94	93	91	90
Horiz.	0°	90	90	90	90	90	90	90	90	90	90	90	90	90

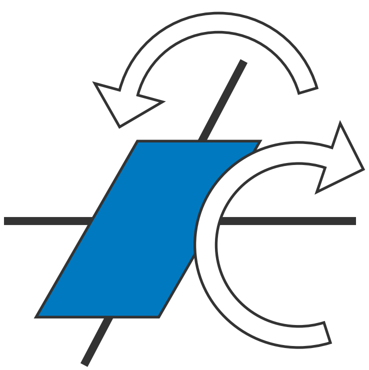
Solar Resource: Tracking



Fixed Tilt (Facing Equator)
- tilt=latitude
- tilt<latitude for summer gain
- tilt>latitude for winter gain



One Axis Tracking around axis (tilted or flat)



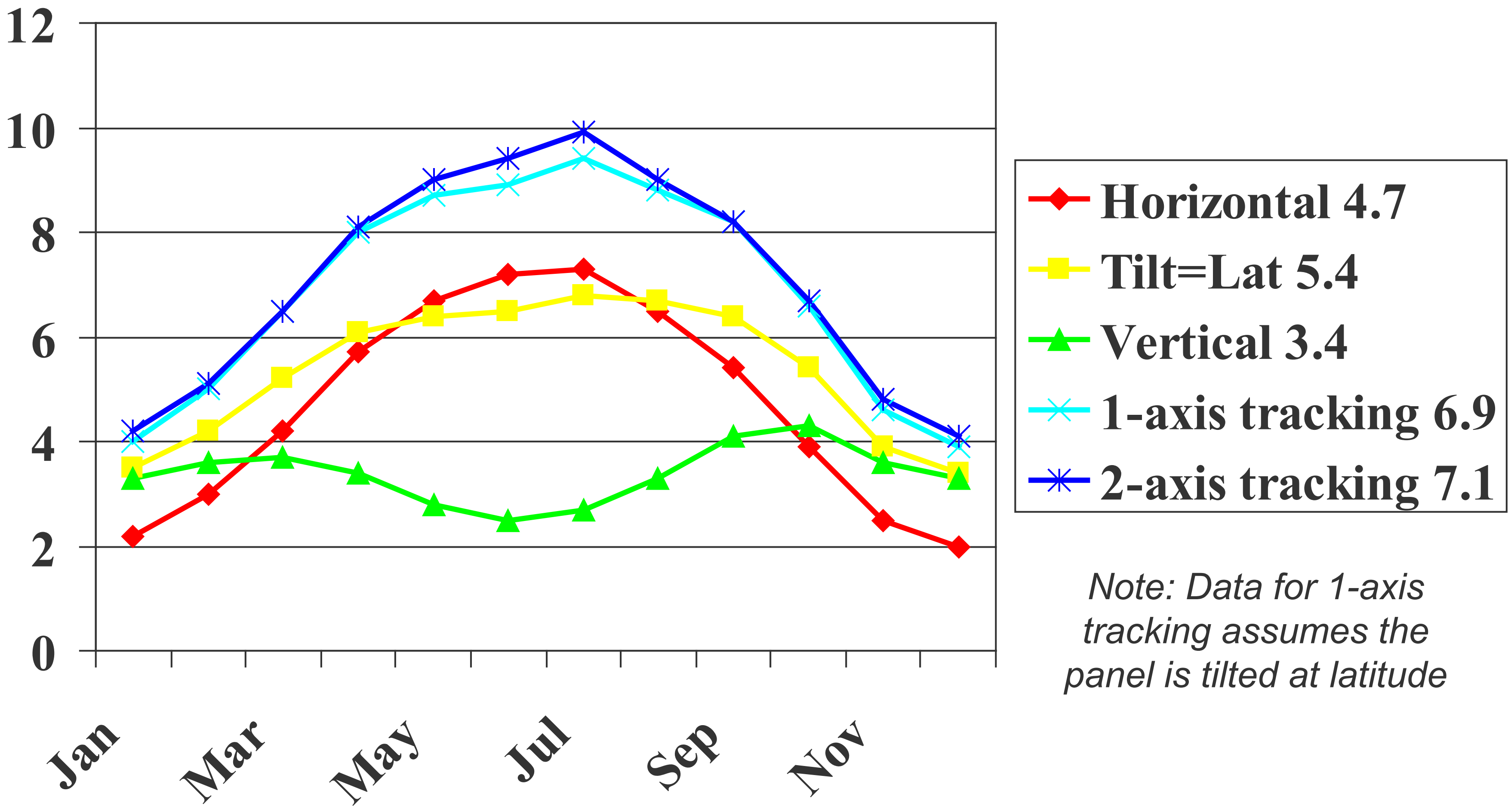
Two Axis Tracking both azimuth and altitude of sun around two axes

Source: Andy Walker

NREL Image Gallery #04827

Solar Resource: Effect of Orientation

Average daily solar insolation (kWh/m²/day)



Note: Data for 1-axis tracking assumes the panel is tilted at latitude

Solar Technologies: Categories

Photovoltaics

NREL Image Library # 00252

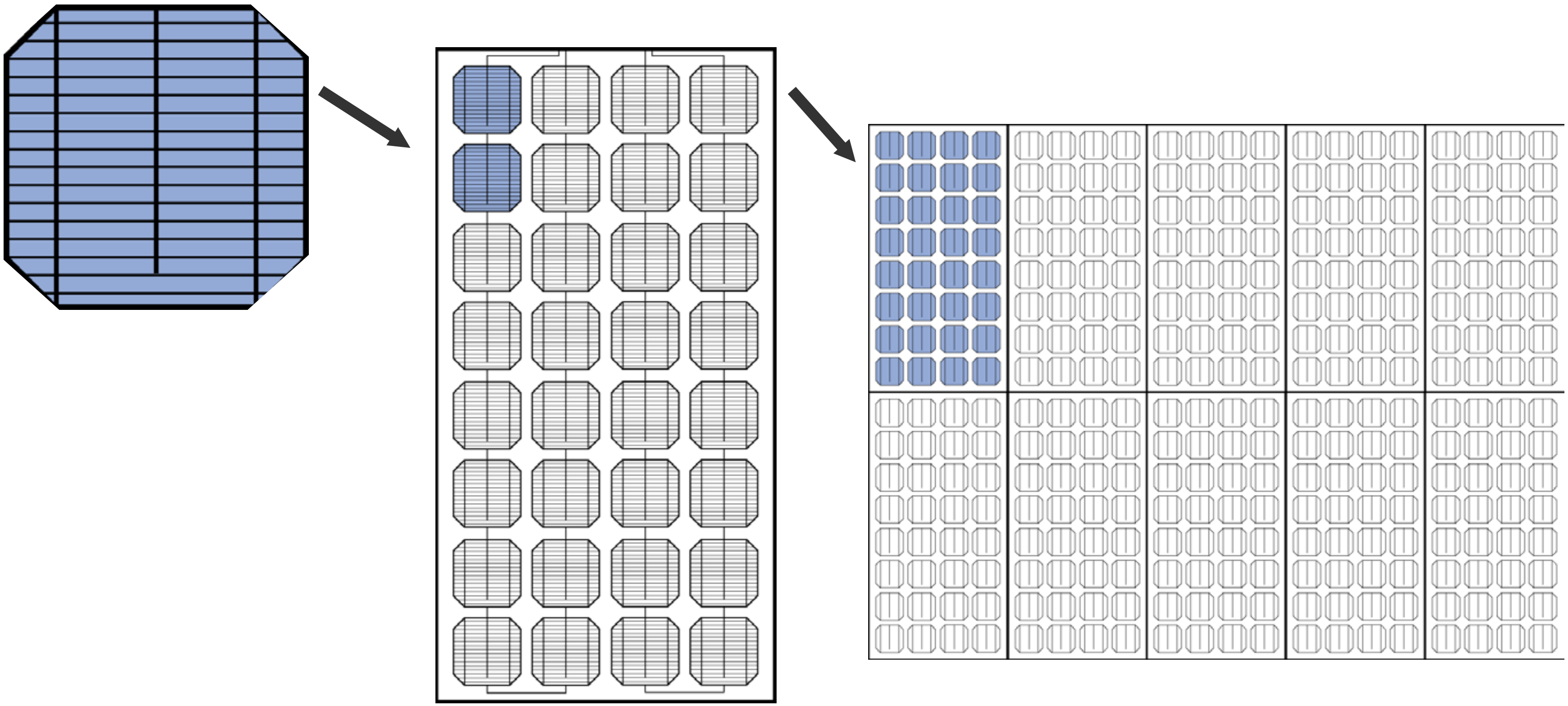
Solar Thermal

NREL Image Library # 09572

Concentrating Solar Power

NREL Image Library # 29169

PV is Modular – Build System to Size Needed



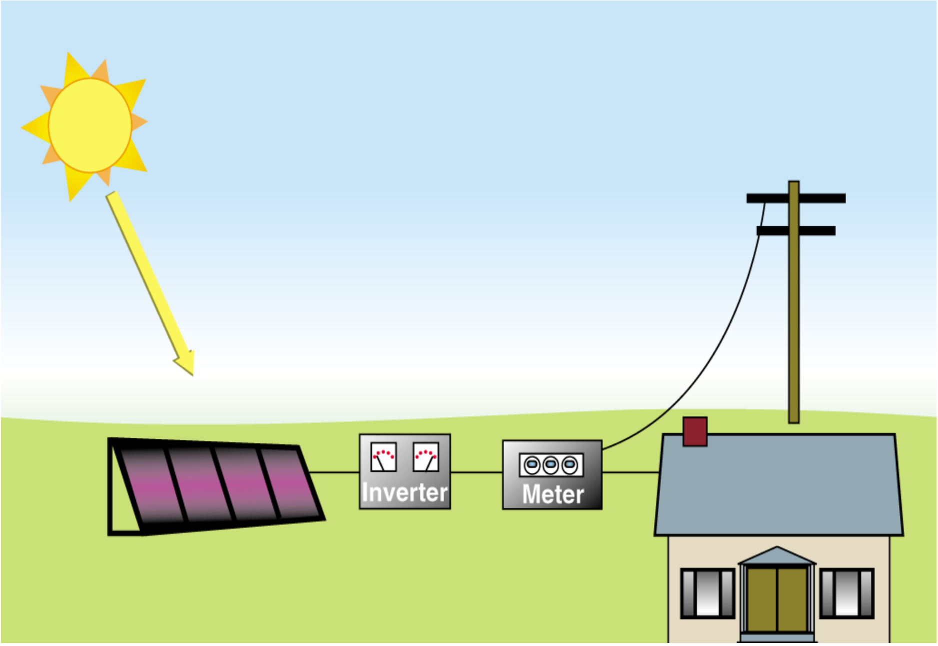
Cells are assembled into ***modules***... and modules into arrays.

Solar Technology (PV): Overview

- Direct conversion of sunlight into DC electricity.
- Panel Efficiency: 10% - 22%
- Panel rating given in watts_{DC}

- DC converted to AC by inverter
- System losses (DC => AC): ~ 15%

- Solid-state electronics, no-moving parts
- PV modules are wired in series and parallel to meet voltage and current requirements
- High reliability, warranties (on panels) of 20-25 years



- System rating described by 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%-40% larger than the AC rating

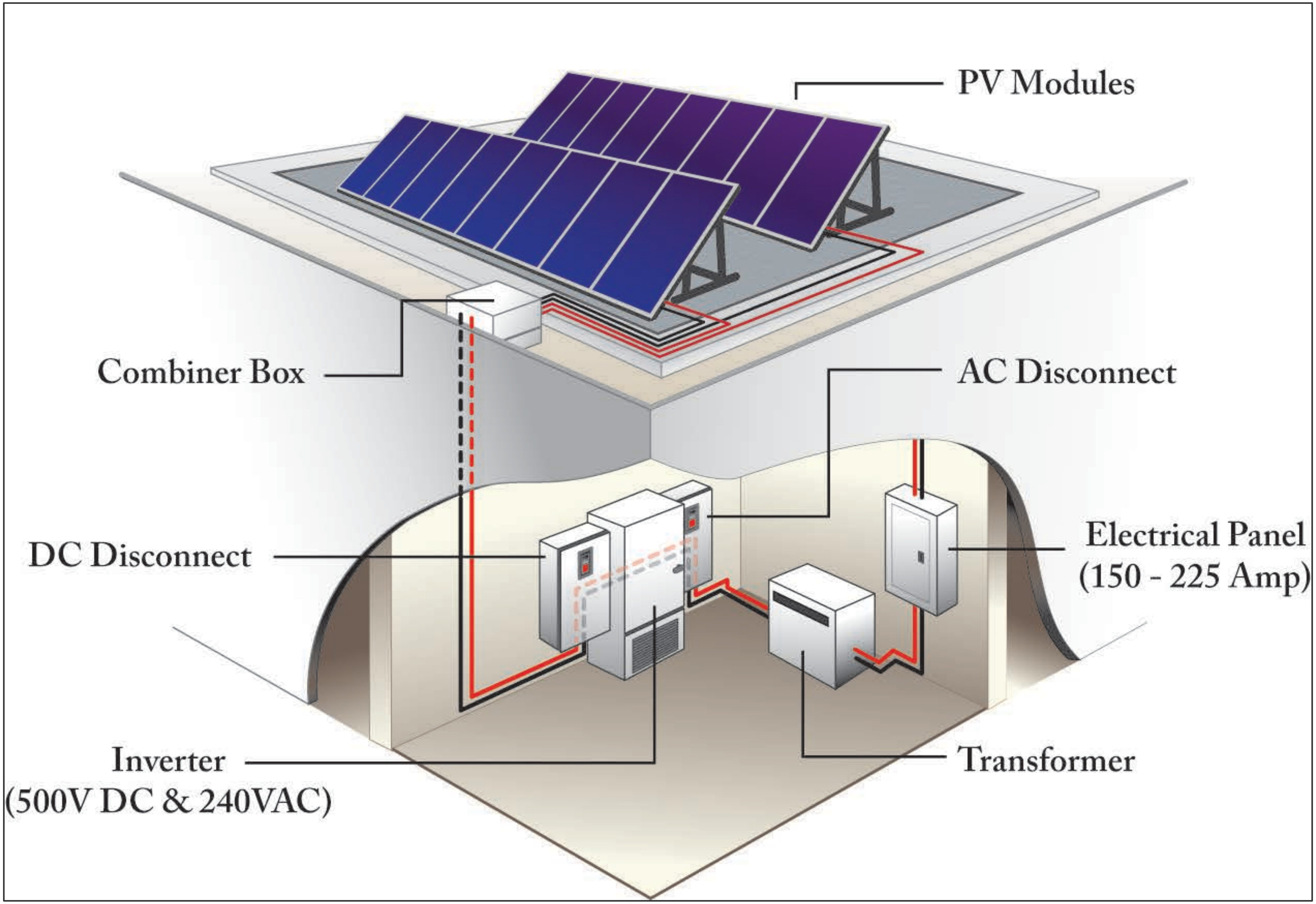
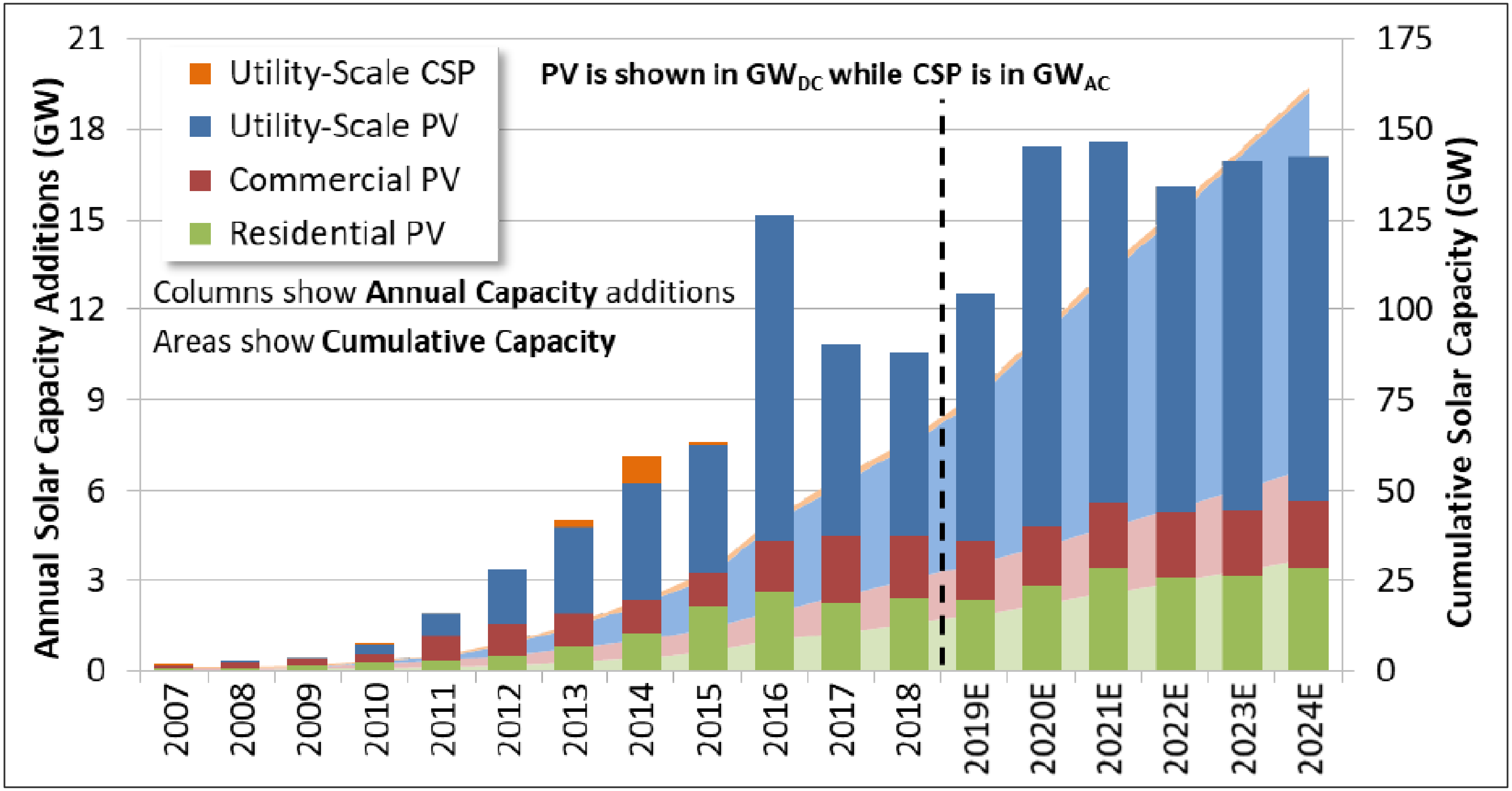


Illustration by Jim Leyshon, NREL

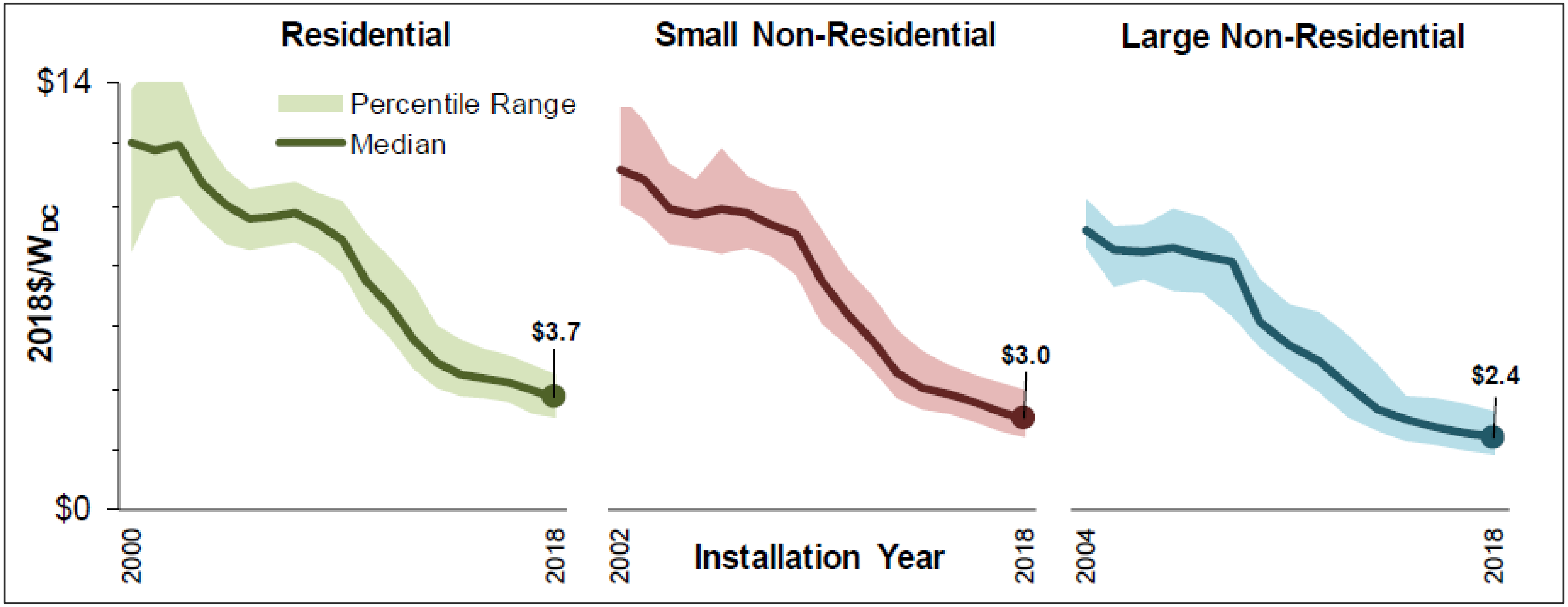
Market – Deployment Trends (U.S.)



Source: Wood Mackenzie/SEIA (2010-2019), LBNL's *"Tracking the Sun" and "Utility-Scale Solar"* databases https://emp.lbl.gov/utility-scale-solar/

Market (PV) – Cost Trends (non-utility)

SOLAR



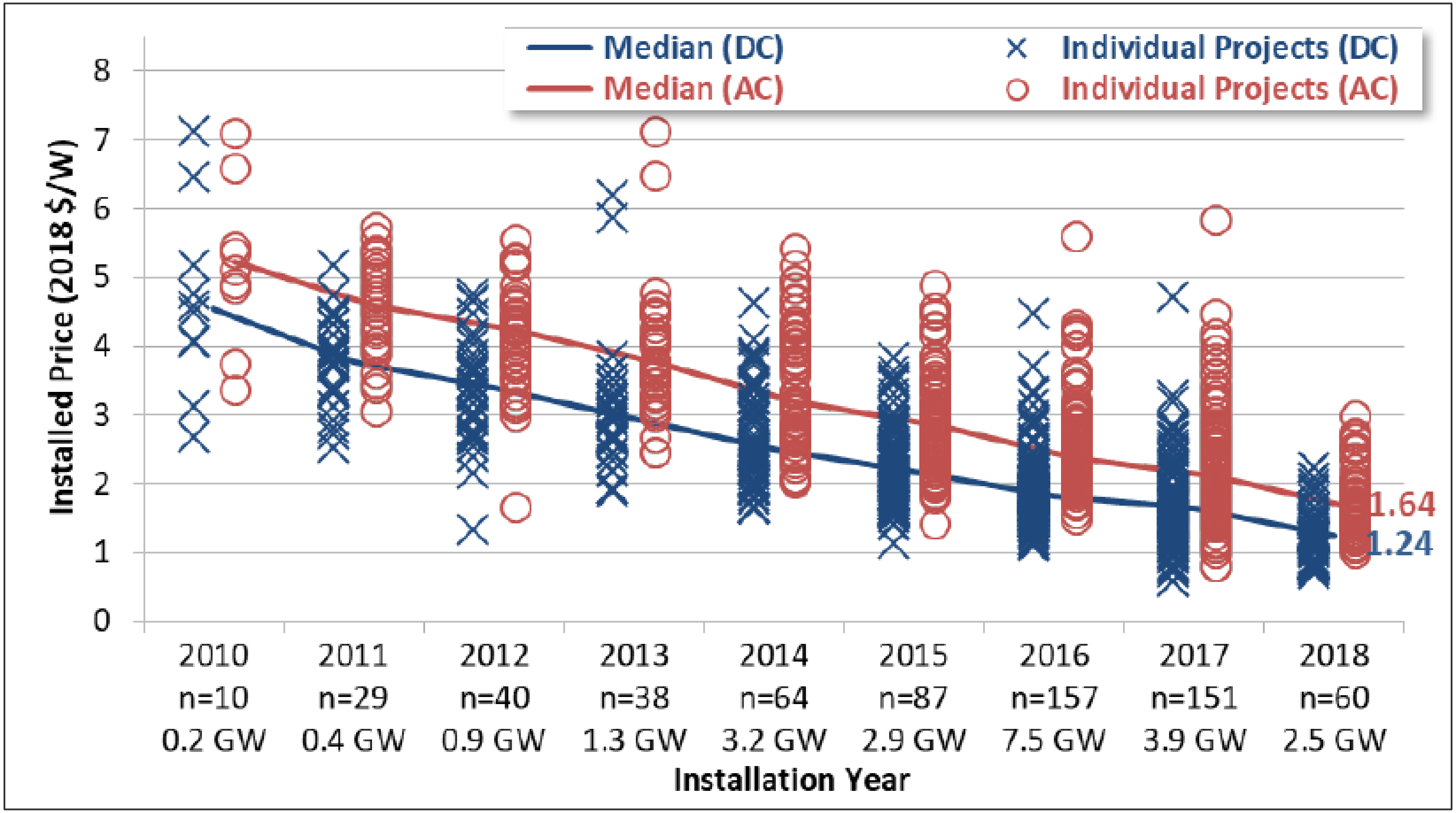
Notes: Percentile Range represents the band between the 20th and 80th percentile values in each year.

- In all sectors, there is a very sharp decline in price from 2009-2014.
- Cost declines ~5%/year are ongoing.

Source: Tracking the Sun - 2019 Edition https://emp.lbl.gov/tracking-the-sun

Market (PV) – Cost Trends (Utility)

SOLAR



Source: Utility Scale Solar - 2019 Edition https://emp.lbl.gov/utility-scale-solar/

Picuris Pueblo Community PV Project

Picuris Pueblo of New Mexico:

Designed to offset 100% of the cost of energy currently used by tribal buildings and residences.   25-yr PPA with Kit Carson Electric Coop. Partnered with Northern Pueblos Housing Authority to provide $1.2 mil Tribe cost share and secure a $1 mil DOE grant.

Source: https://www.energy.gov/indianenergy/articles/community-solar-meet-100-energy-costs-new-mexico-tribe

Solar: Recap

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

Technologies: Photovoltaics (PV), Concentrating Solar Power (CSP), Solar Thermal

PV Panels/Arrays: Described in terms of watts or kW. Panel conversion efficiency typically 10% - 22%

Facility Size:

- **PV:** Utility, Distributed Generation (DG)
- **CSP:** Utility (mostly)
- **Solar Thermal:** DG

Space Utilization Planning Factors

- **Residential Rooftop:** ~10 watts/square foot
- **Ground mounted:** 5-8 acres per MW_{DC}

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

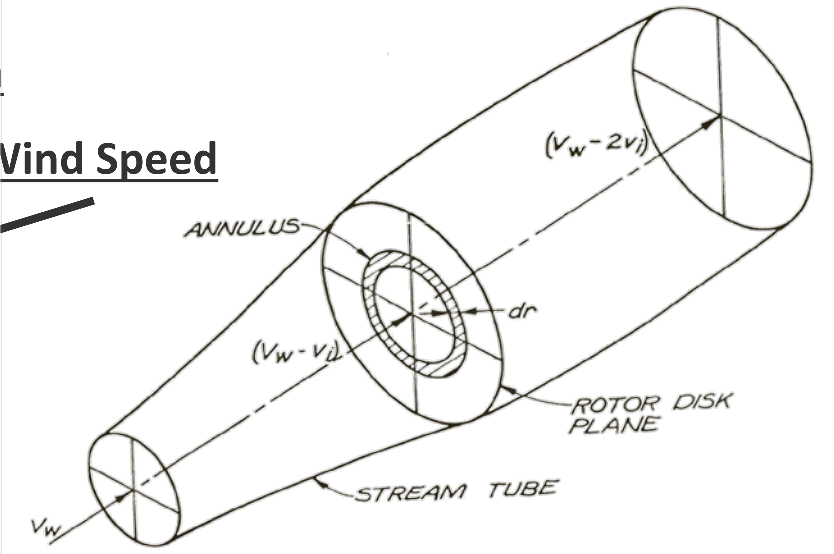
Wind Energy

Resource: Power in the Wind

Efficiency Air Density Rotor Area Wind Speed

$$WindPower = C_p(\frac{1}{2}\rho A V^3)$$

$$C_{P\max} \cong 0.59$$ ***The Betz Limit***



Wind power is proportional to velocity cubed (V^3):

– 25% higher wind speed ≈ **2 times the power** available

– If wind speed is doubled, power increases by a **factor of 8** ($2^3 = 8$)!

Small differences in average speed cause big differences in energy production!

Looking for ways or locations to increase wind speeds will pay big dividends!

Resource: Power Density

$$\text{Power Density} = P/A = 0.5\ \rho\ v^3$$

Wind Class	W/m^2 at 50 m	Average Wind speed at 50 m
1	0 - 199	0 - 5.9 m/s
2	200 - 299	5.9 - 6.7 m/s
3	300 - 399	6.7 - 7.4 m/s
4	400 - 499	7.4 - 7.9 m/s
5	500 - 599	7.9 - 8.4 m/s
6	600 - 800	8.4 - 9.3 m/s
7	> 800	> 9.3 m/s

Q: How is power density calculated?

A: Measure wind speed and do math

Wind Resource: Characteristics

Mean wind speed – average annual (or longer term) wind speed
[Is this a windy location?]

Wind speed distribution – how many hours per year (y) does the wind blow at (x) m/s?
[Do I have enough times to make electricity cheaply to pay my loans?]

Vertical wind shear – how much the wind speed changes with height above the ground?
[How tall of a tower do I need?]

Direction – *how often and how strong are the winds from particular directions?*
[Do I have good "fetch" in the direction the most energetic wind usually comes from?]

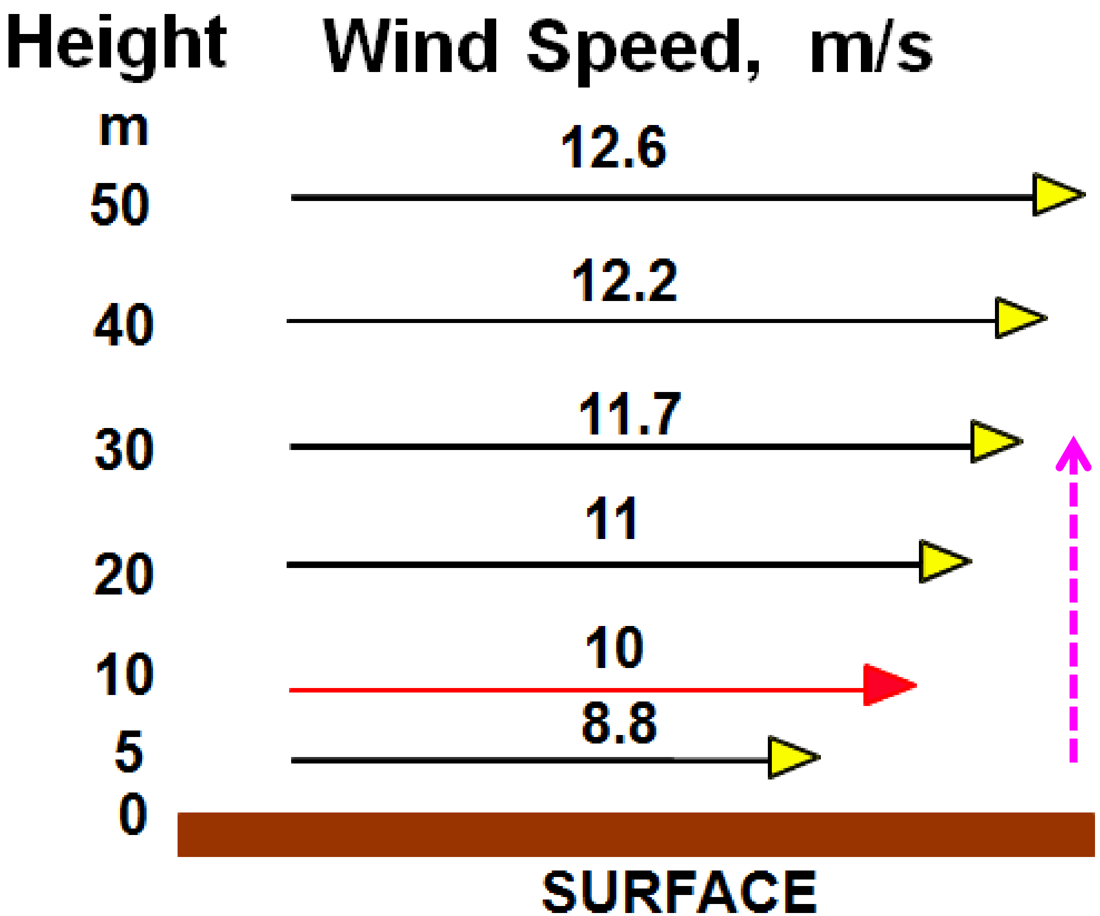
Wind Resource: Characteristics

Diurnal wind distribution – what time of day has the most wind energy?
[Can I make electricity when I need it?]

Seasonal wind distribution – how many months/what time of year has the strongest wind?
[When I can generate most cheaply, when to I need it most, how does it compare to solar and hydro? And the load? When do loads peak?]

How turbulent is the wind?
[How much will turbulence cost me in annual O&M and unplanned repairs?]

Resource: Wind Shear

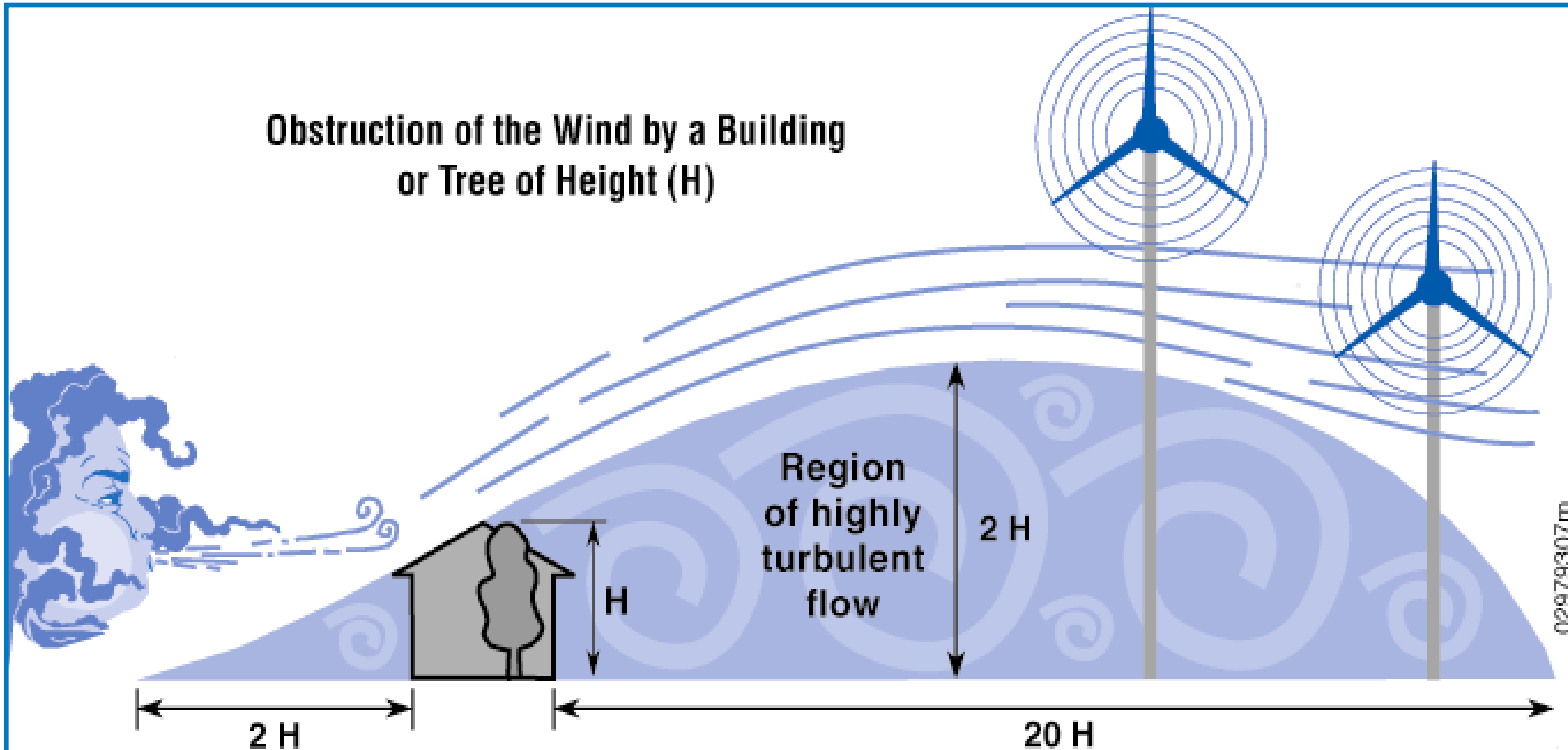


Increasing the wind speed from 8.8 to 11 m/s (25% increase), doubles the available power in the wind!

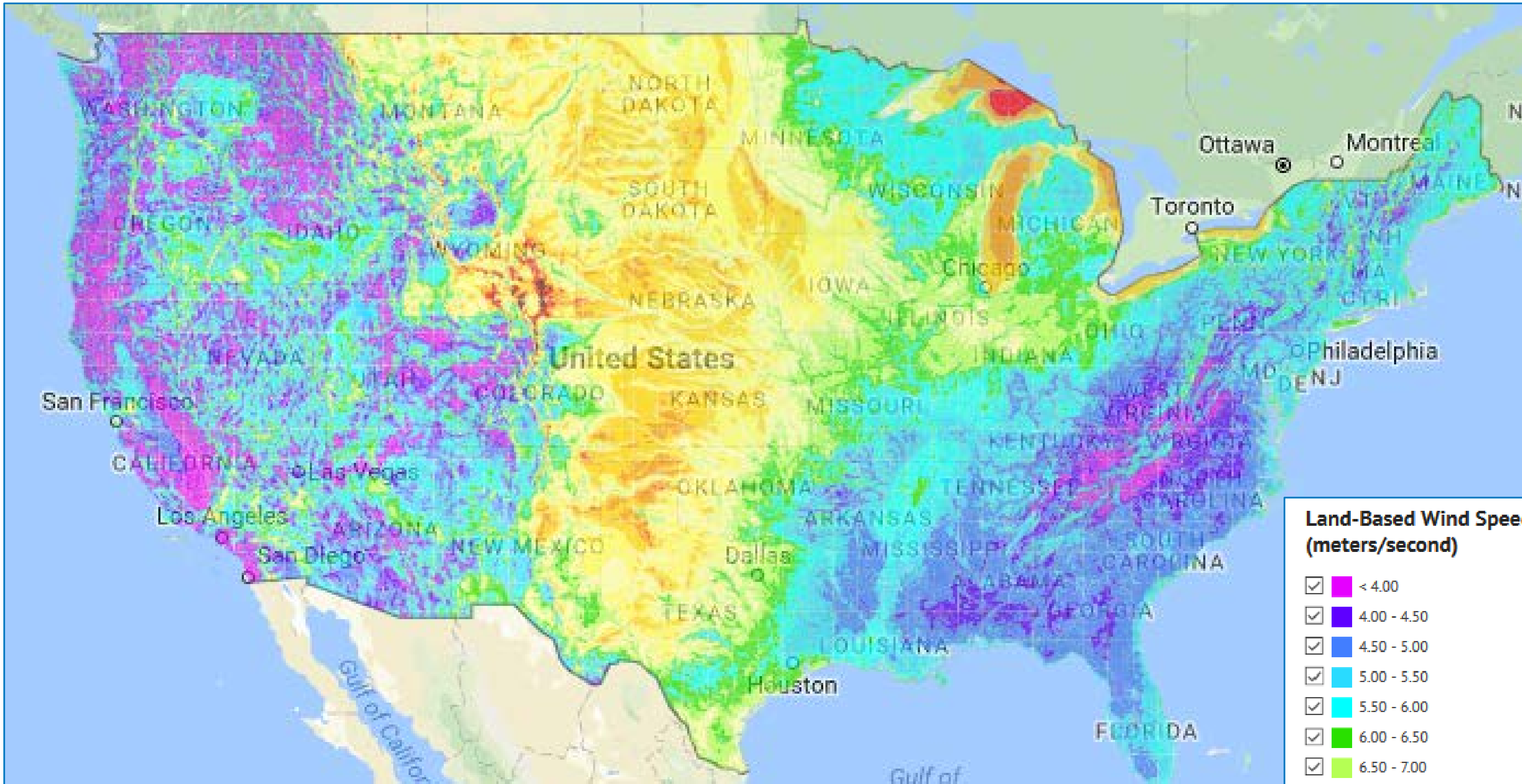
That is why "taller towers" is often the first answer to "how can the wind turbine energy production be increased at this location?"

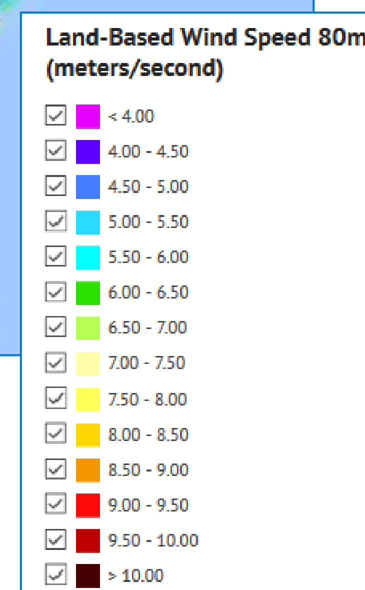
Courtesy of Alternative Energy Institute

Resource: Turbulence & Micrositing



Resource: Wind Map

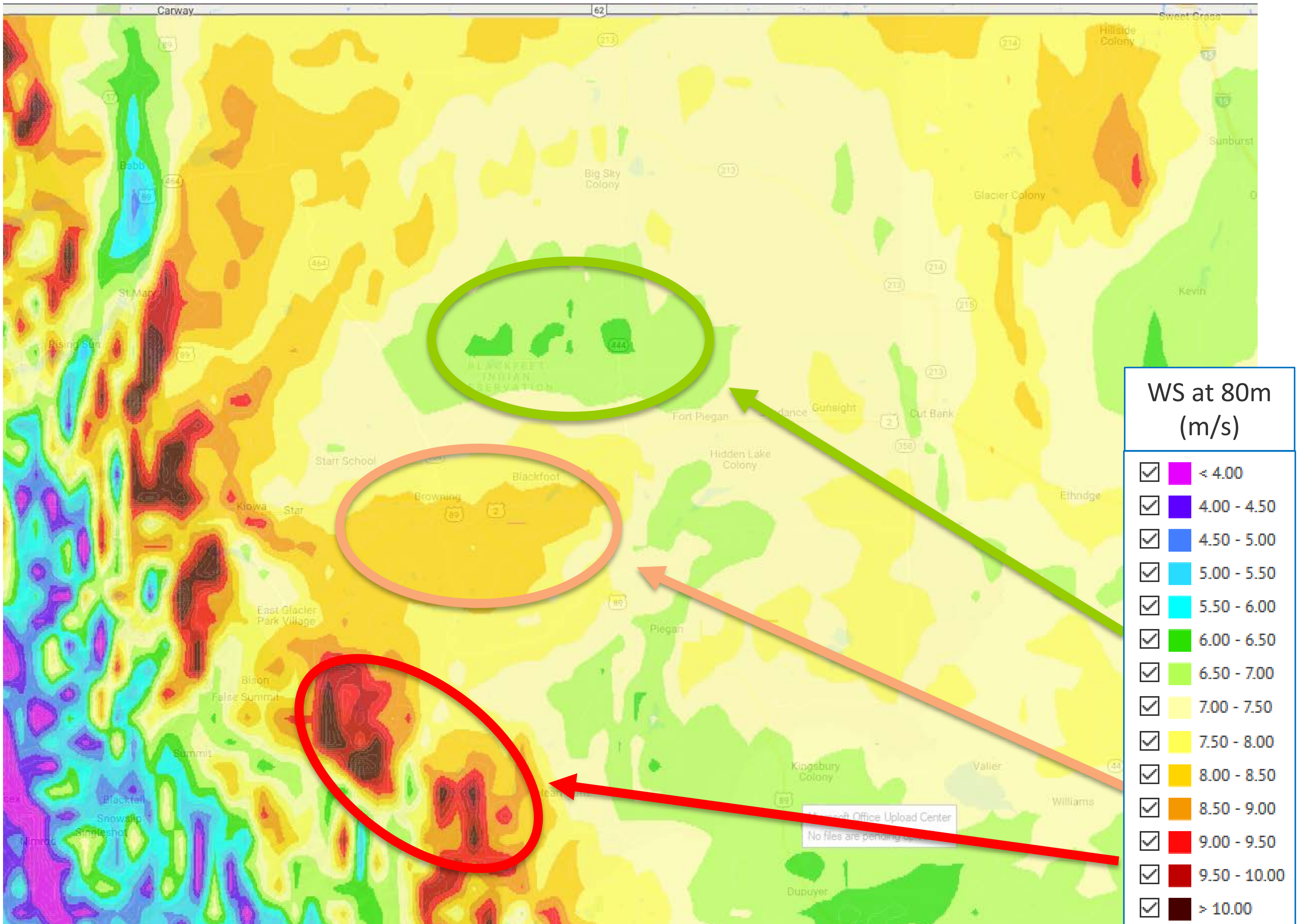




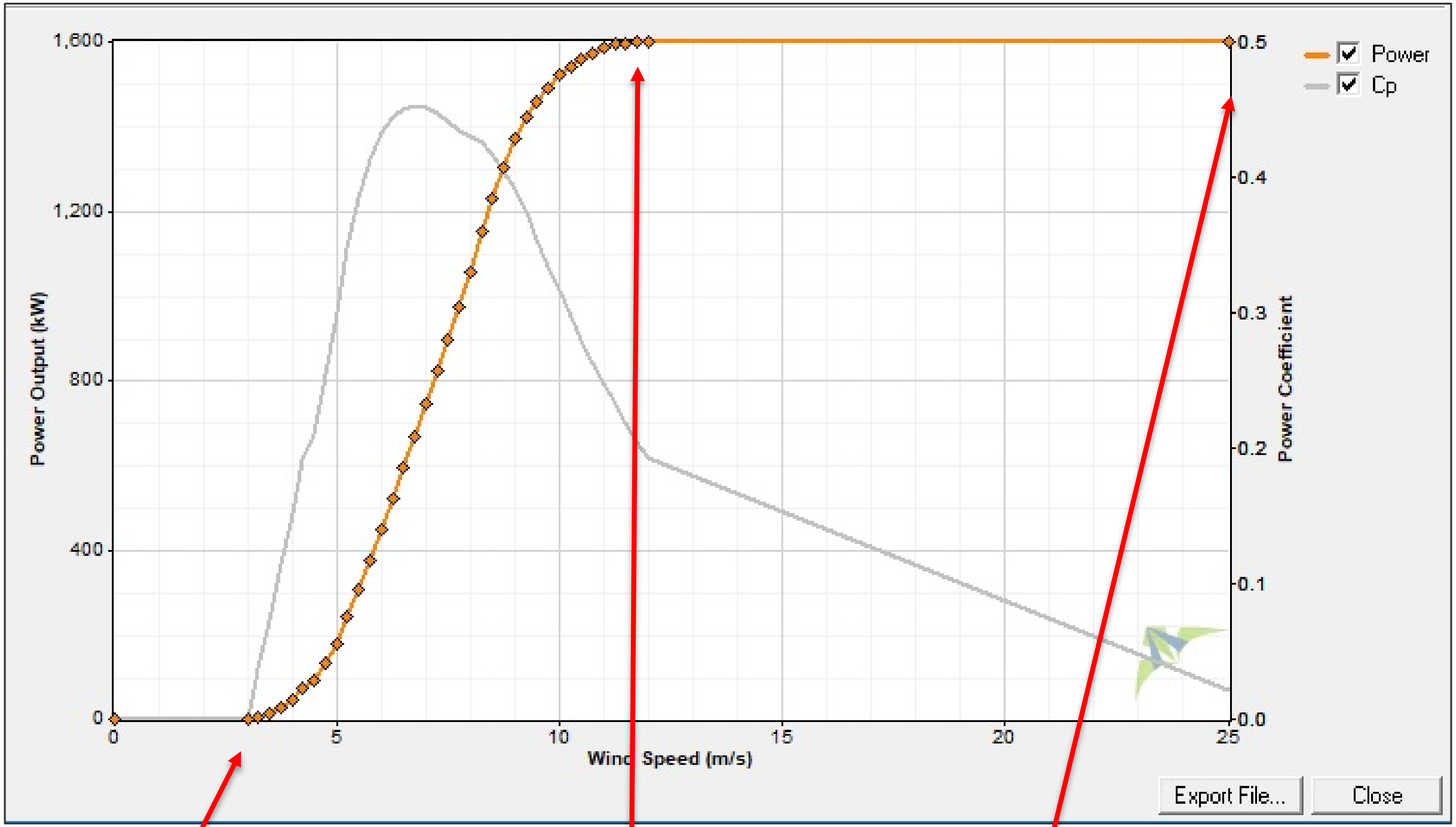
Wind Prospector is a good place to start investigating the wind resource at no cost.

Source: https://maps.nrel.gov/wind-prospector

Resource: Close Up Wind Map



Technology – Power Curves

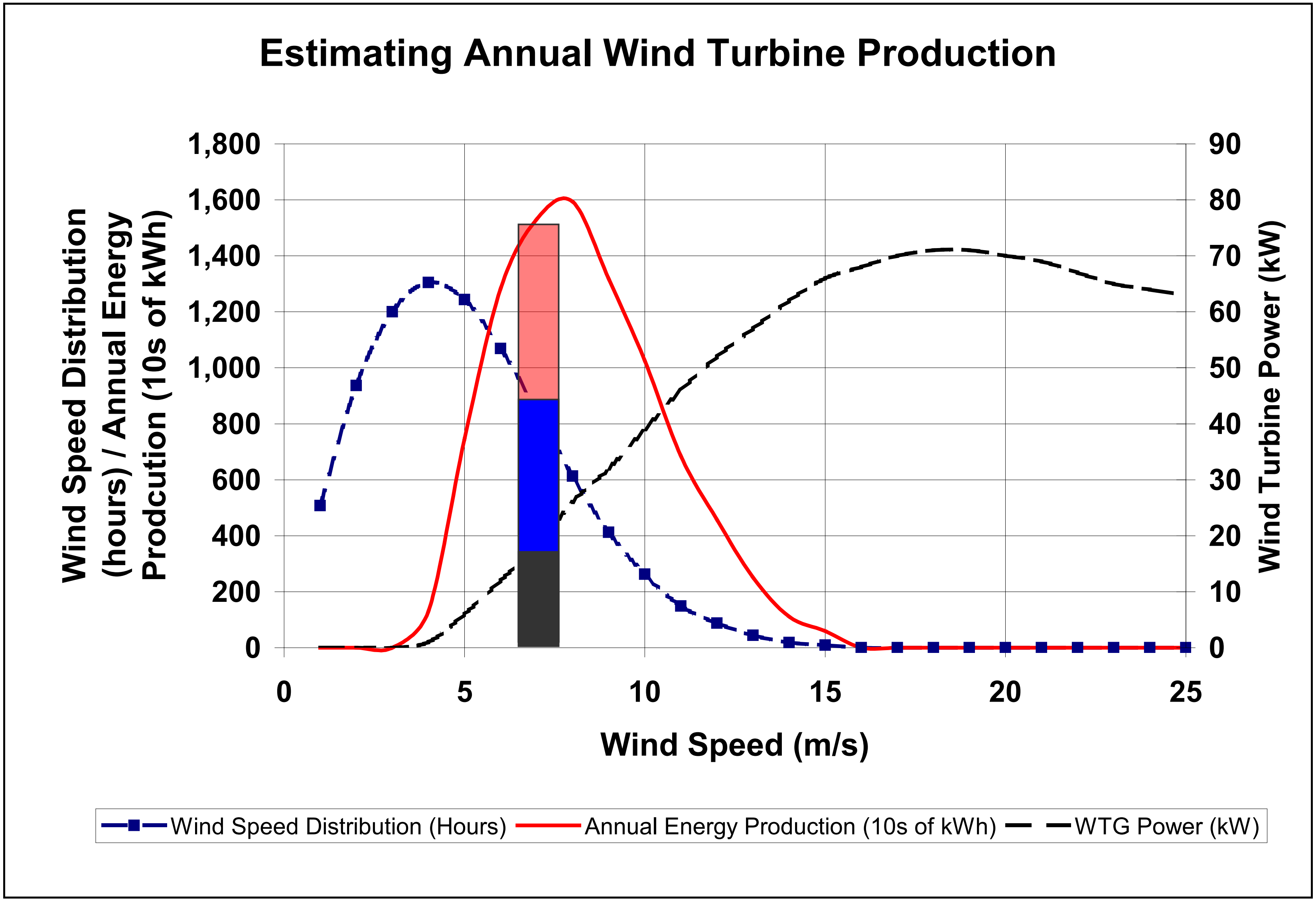


Cut In

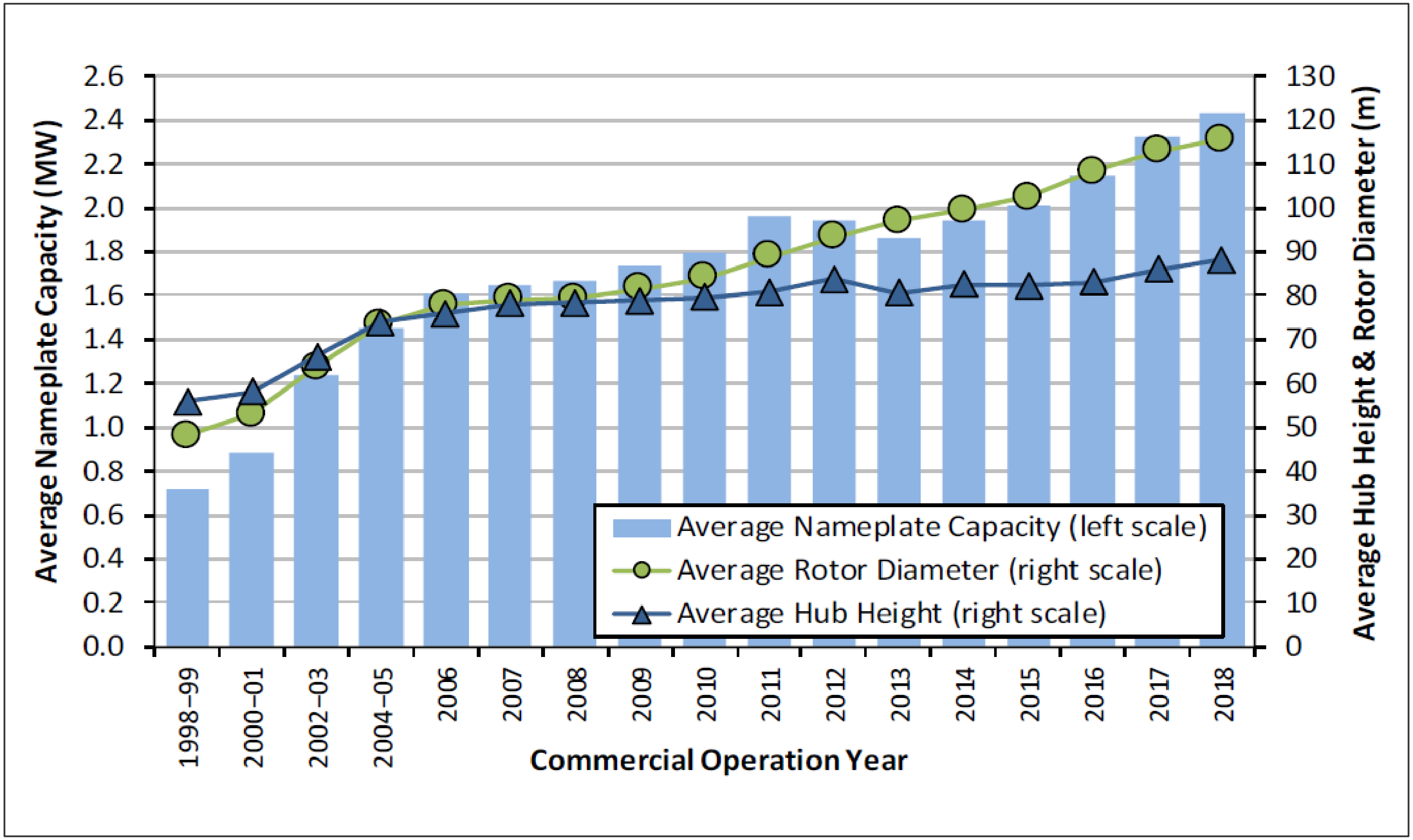
Peak/rated power

Cut Out

Technology: Turbine Energy Production



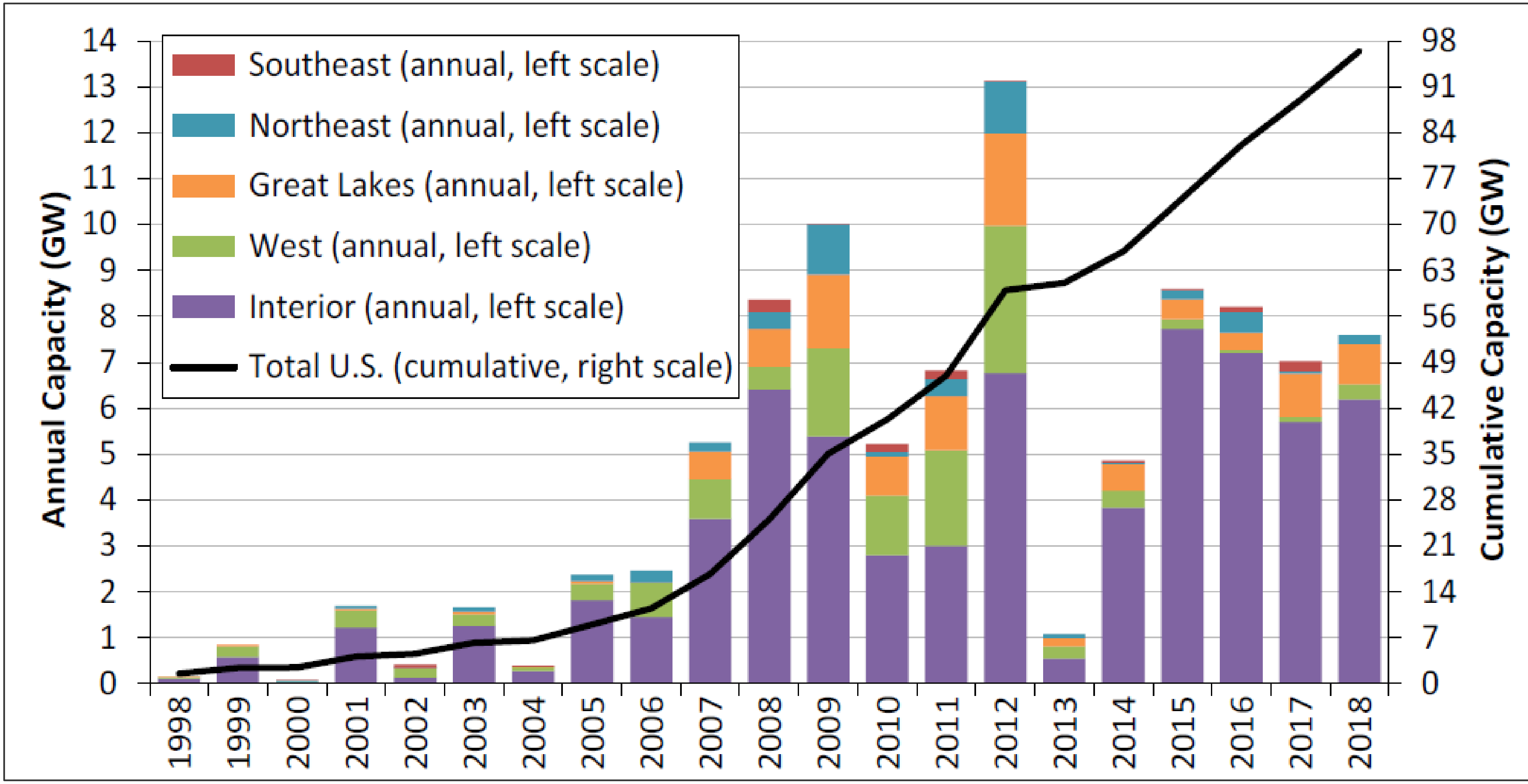
Technology: Turbine Trends (Utility Scale)



Growth in average rotor diameter and turbine nameplate capacity have outpaced growth in average hub height over the last two decades

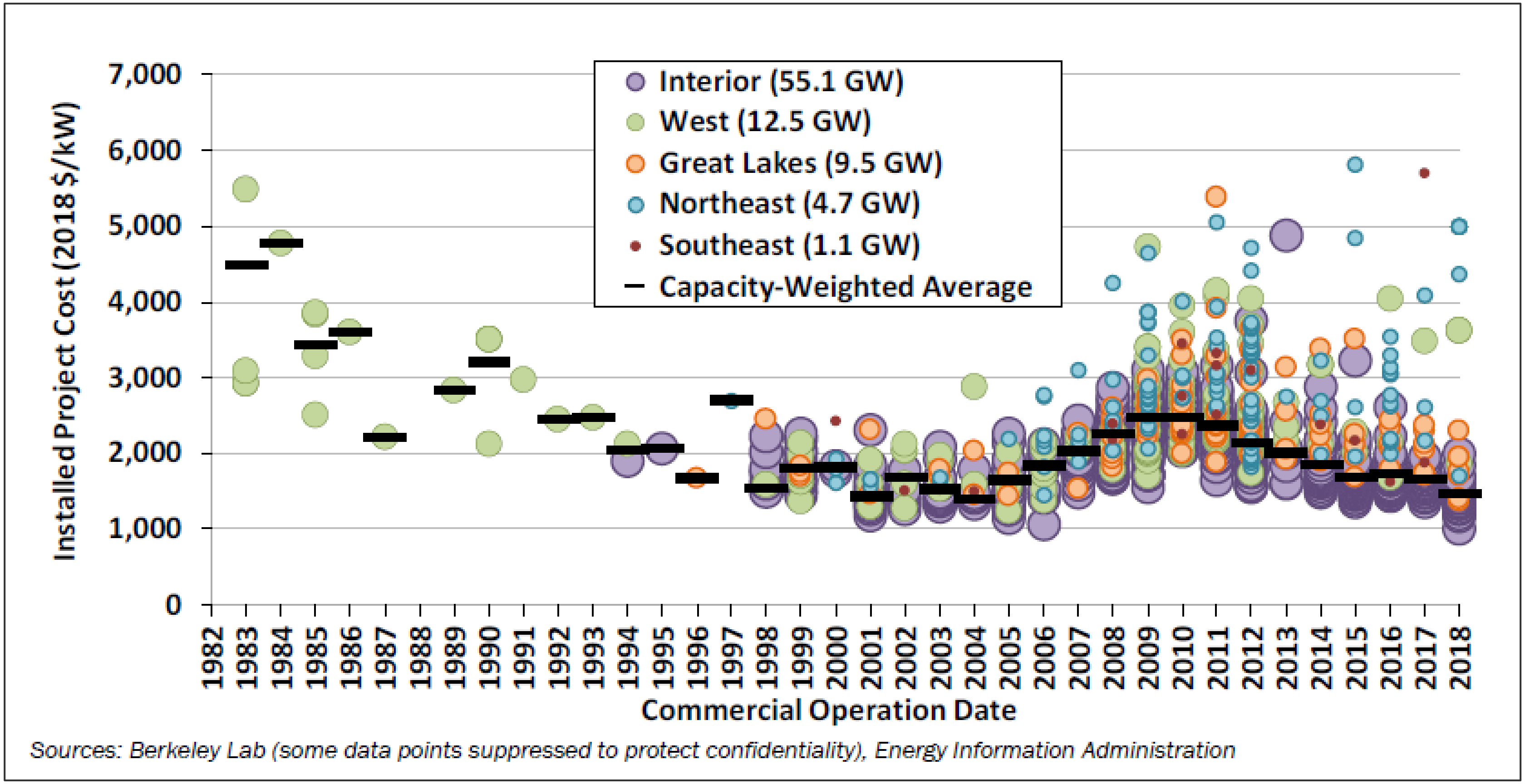
Source: *2018 Wind Technologies Market Report* https://www.energy.gov/eere/wind/downloads/2018-wind-technologies-market-report

Market: Deployment Trends (Utility Scale)



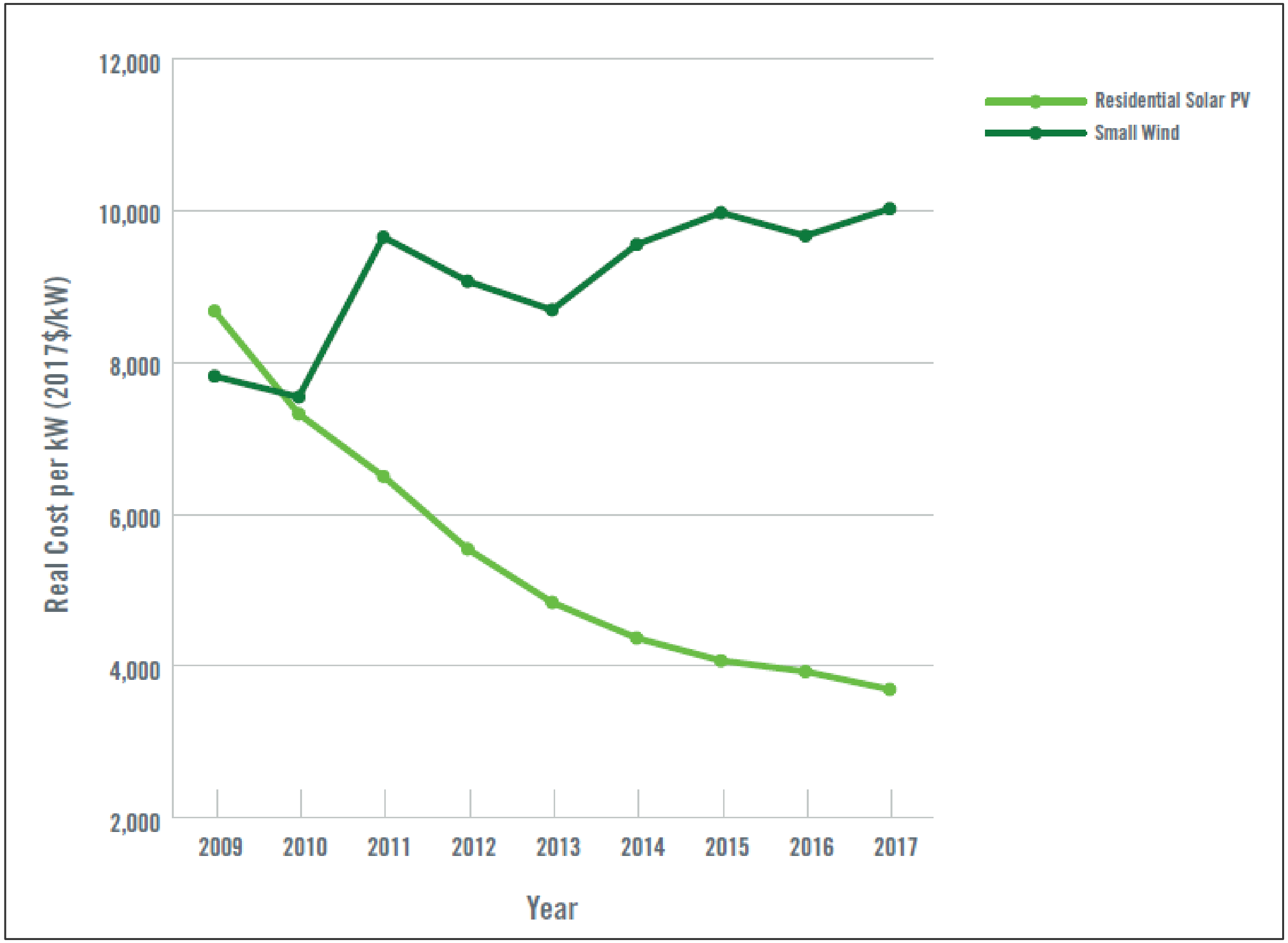
Source: *2018 Wind Technologies Market Report* https://www.energy.gov/eere/wind/downloads/2018-wind-technologies-market-report

Wind Project Cost Trends (Utility Scale)



Source: *2018 Wind Technologies Market Report* https://www.energy.gov/eere/wind/downloads/2018-wind-technologies-market-report

Wind Project Cost Trends (Distributed)



Source: *2018 Distributed Wind Market Report* https://www.energy.gov/eere/wind/downloads/2018-distributed-wind-market-report

Seneca Nation 1.7 MW Wind Turbine

Created Seneca Energy LCC to facilitate reaching a range of tribal energy goals.

Mission includes:

- Lowering the cost of energy,
- Training an energy workforce,
- Building renewable energy assets,
- Securing critical energy infrastructure,
- Promoting energy sovereignty and self-sufficiency, and
- Preserving the environment

Significant Achievements:

- Utilizing statewide net metering policy SNI created a virtual utility service to better balance energy costs across 3 distinct tribal locations/service areas.
- Will save Seneca Nation $360k annually in electricity costs

Source: https://www.energy.gov/indianenergy/articles/seneca-nation-celebrates-commissioning-17-mw-wind-turbine-doe-support

Wind: Recap

Resource: Ranges from < 20 watts/m^2 to > 600 watts/m^2. The wind resource varies by height and is affected by "ground clutter".

Wind Turbines: Typically described in terms of peak power or rotor size

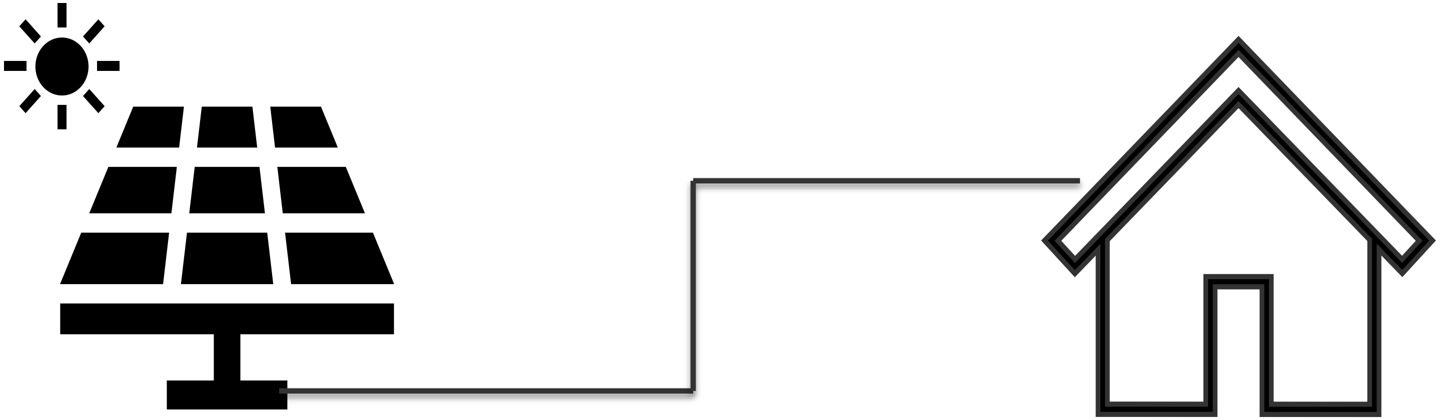
Facility Size: Utility and DG

Market Status:

- **(Utility):** Significant cost reductions and performance improvements in recent years have spurred an explosion of installations in the U.S. and worldwide
- **(DG):** Limited performance improvements and almost no capital cost reductions have resulted in a stagnant market.

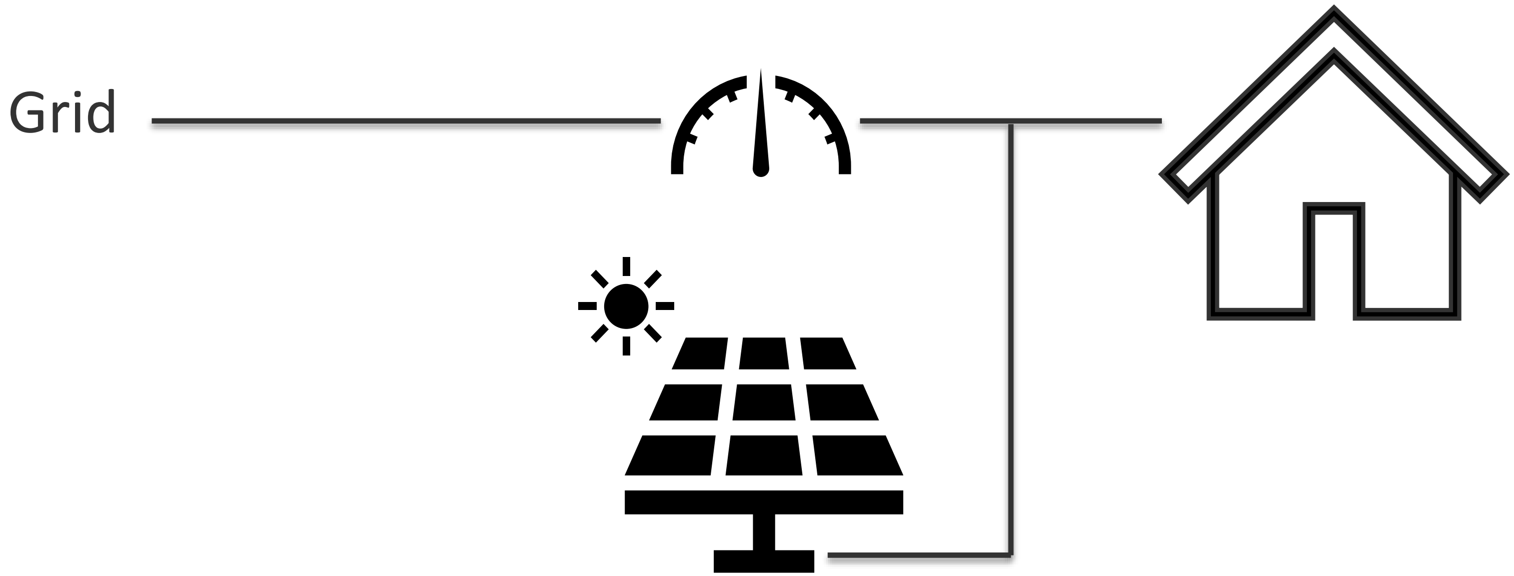
Project Types

Project Types – Off grid



- Facility serves a one or more off-grid loads
- Typically paired with a battery

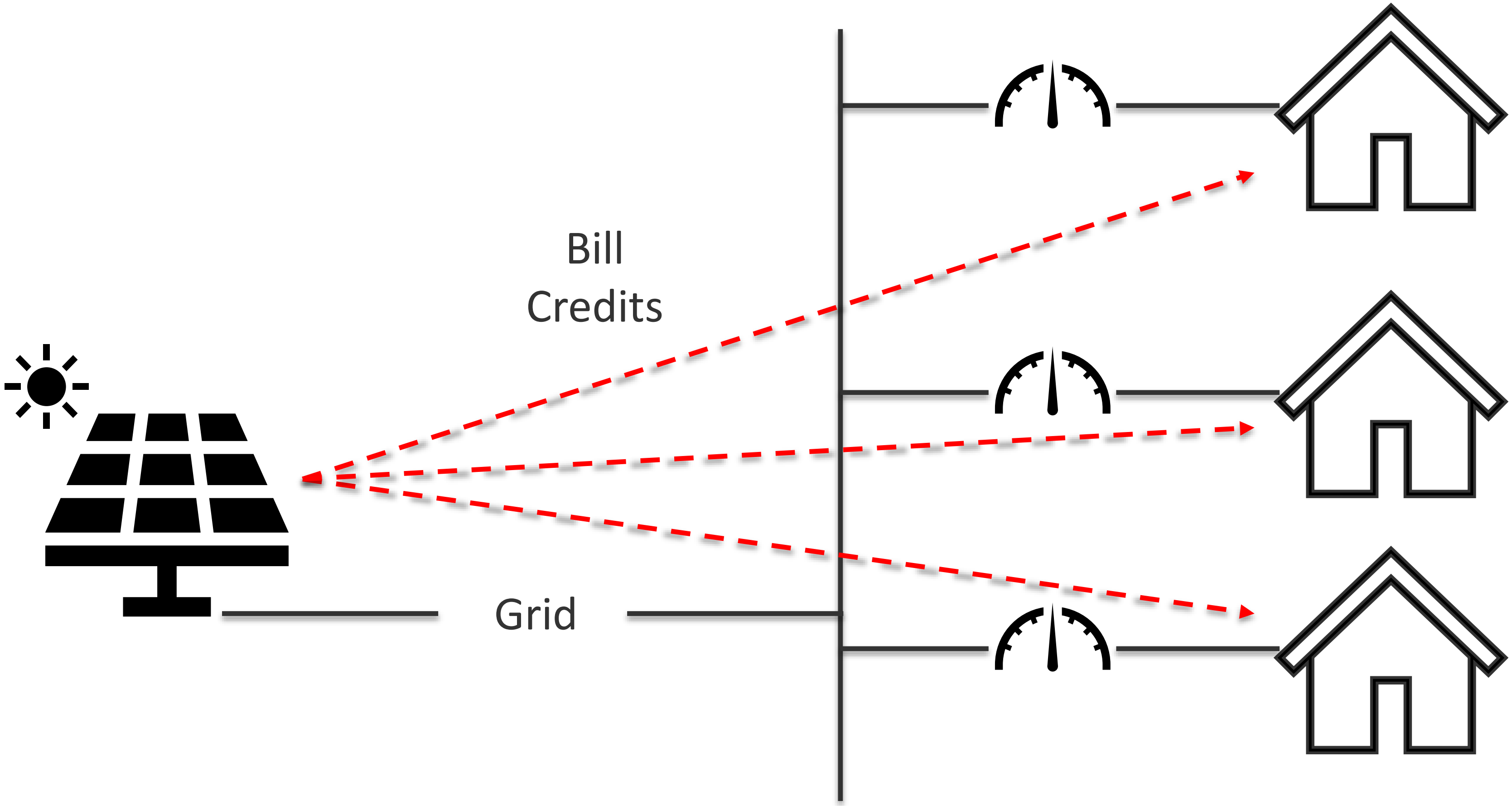
Project Types – Behind the Meter



Project Types – Behind the Meter

- Facility is interconnected on the customer side of the meter
- Facility serves a single (metered) load (with the occasional example of aggregate net metering)
- Size: ~2 kW_{DC} - 1+ MW_{DC}
- Facility typically is usually sized no larger than what is needed to serve the load
- Financial value is equal to the retail electricity rate
- Can be paired with a battery to provide backup generation

Project Types – Front of the Meter (Community Solar)



Project Types – Front of the Meter (Community Solar)

- Only done with solar
- Facility is interconnected to the local distribution system
- Facility “virtually” serves one of more loads.
- Common way for low income households or facilities that aren’t suitable for on-site PV to gain access to PV
- Size: ~100 kW_{DC} - 1+ MW_{DC}
- Can be owned (sponsored) by utility or third party
- Financial value is equal to the retail electricity rate
- Not allowed in all jurisdictions

Project Types – Front of the Meter (Utility Solar)

- Facility is interconnected to the transmission grid or local distribution system
- Size: ~1 MW_{DC} - 500+ MW_{DC}
- Can be owned by utility or third party
- Financial value is equal to the **wholesale** electricity rate

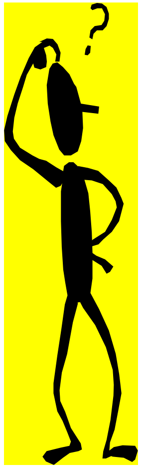
Presentation Recap

Examined solar and wind technologies

- Resource , Technology, Market Status
- Both solar & wind can be deployed at a variety of scales
- Both technologies have seen dramatic cost reductions & performance improvements

Examined project types

- Distributed scale (retail): connected to a specific load
- Utility scale (wholesale): connected to the grid
- “Community solar gardens”: connected the grid, financial benefits credited (at ~retail) for those who have purchased a share.



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Tony Jimenez

tony.jimenez@nrel.gov

work: 303-275-4849