Wind - Solar – Biomass - Micro-hydro and Battery Storage – Distributed Applications

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NREL
Oct 31, 2018

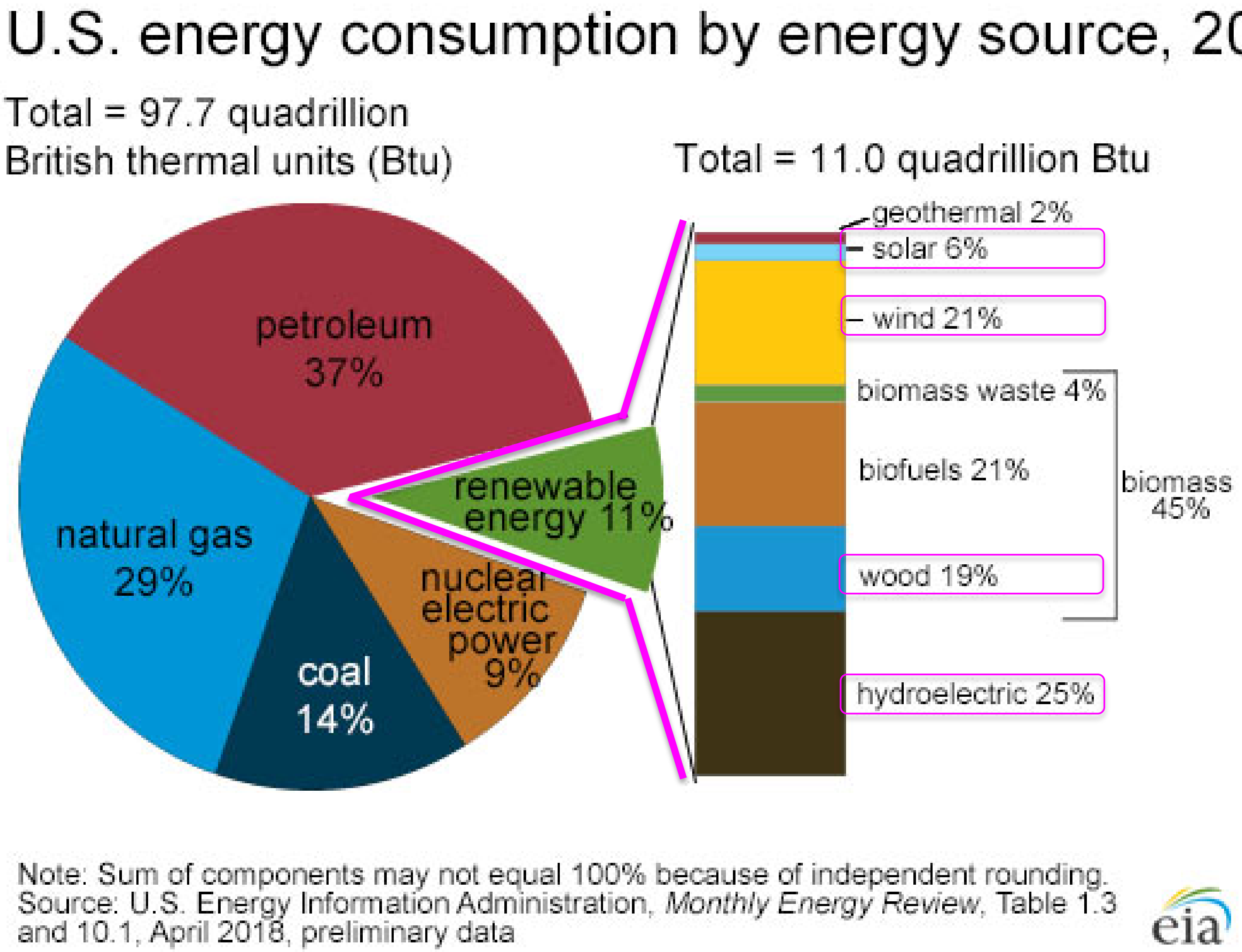
Renewable Energy Framework

Outline

- Energy & Electricity - Where Are We Now – Big Picture
- Wind Basics
  - Wind Resource
  - Wind Turbines for Distributed Applications
- Solar Basics
  - Solar Resource
  - PV Technologies for Distributed Applications
- Biomass for Heating Basics
  - Biomass Resource
  - Biomass for Heating Applications
- Micro-hydro Basics
  - Micro-hydro Resource
  - Micro-hydro Distributed Applications
- Batteries – Energy Storage
  - Batteries Today and Looking Forward

Where Are We Now?

Challenges of Higher RE Penetration



The energy sectors

- Electric Power (38%)
- Transportation (29%)
- Industrial – Process / HVAC / Other (22%)
- Commercial / Residential (11%)

Current Contribution of Renewables

The energy sectors

- Electric Power (38%)
- Transportation (29%)
- Industrial – Process / HVAC / Other (22%)
- Commercial / Residential (11%)

Coal (34%)
Natural Gas (26%)
Nuclear (23%)
Renewable Energy (17%)

Wind	6.2%
Solar	1.8%
Hydro	7.4%

The hydropower (7.4%) is mostly large utility-scale dams built more than 70 years ago [Grand Coulee, Hoover, John Day, etc]. 95% of wind & solar is last 13 years.

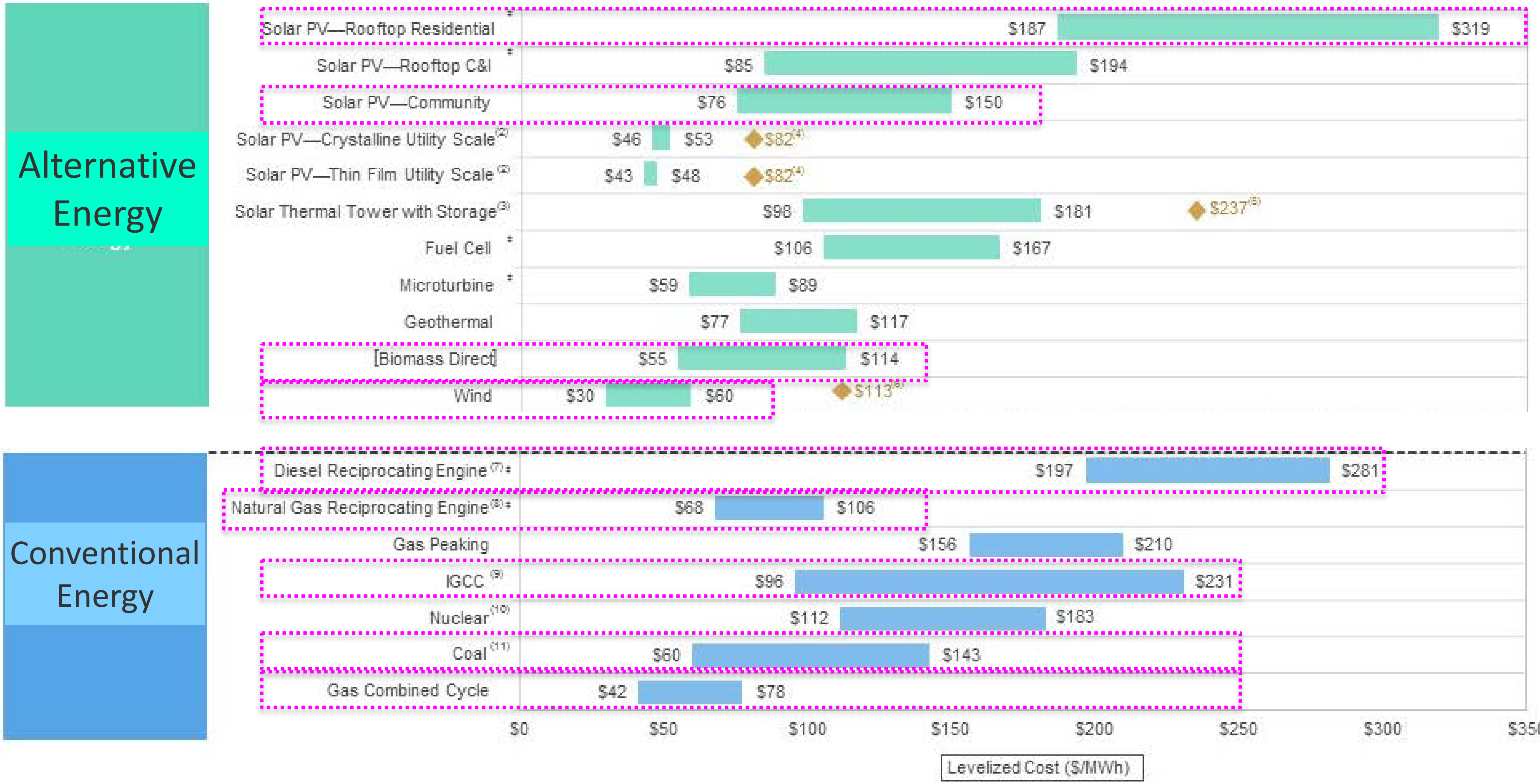
DOE's Wind Vision cites a penetration goal of 20% wind by 2030. 6.2% equates to 89 GW (end of 2017).
To get to 20% U.S. will need 287 GW by 2030.

DOE's SunShot program does not cite deployment or penetration goals by 2030.
The cite energy cost goals: $0.05/kWh for residential PV; $0.04/kWh for commercial PV and $0.03/kWh for industrial PV. It is anticipated that at those LCOE levels, PV penetration rates across each market will be high.

Source: https://www.eia.gov/totalenergy/data/monthly/pdf/flow/css_2017_energy.pdf

Current Sources & Costs of Energy

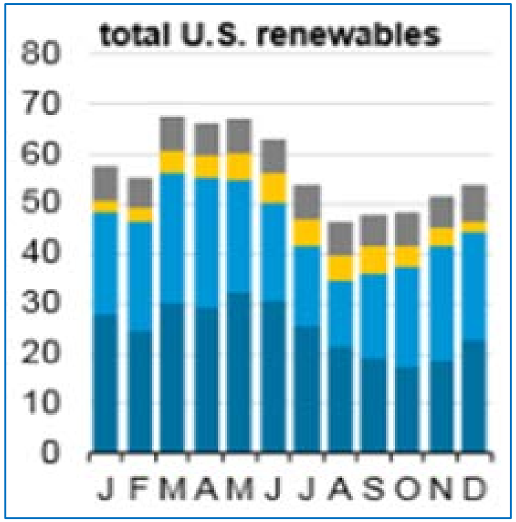
Unsubsidized Levelized Cost of Energy Comparison

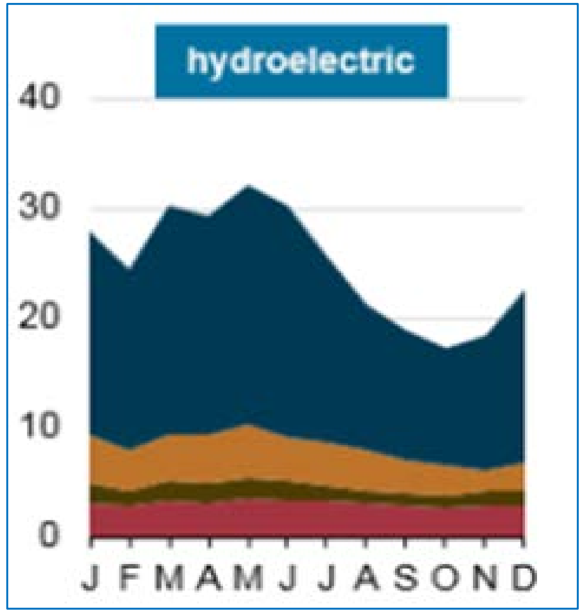


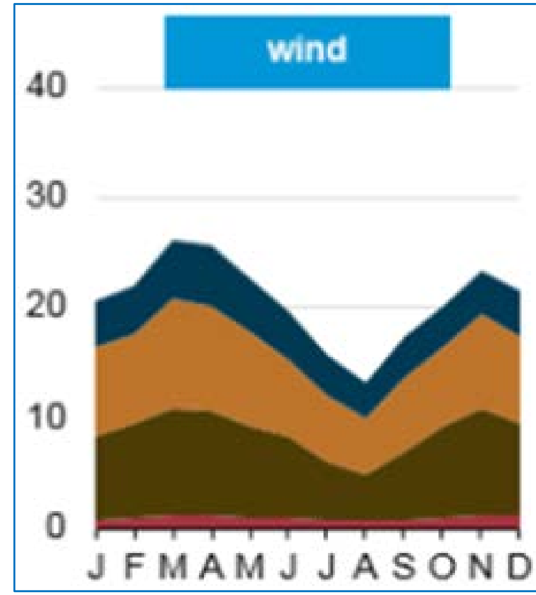
Source: https://www.lazard.com/perspective/levelized-cost-of-energy-2017/

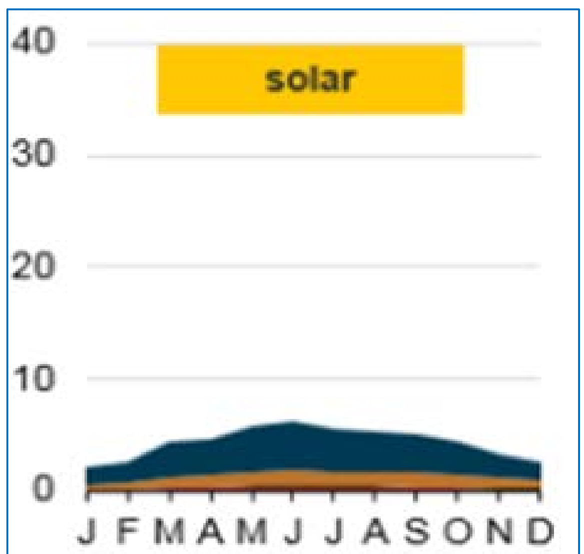
Utility-Scale Renewable Generation by Region

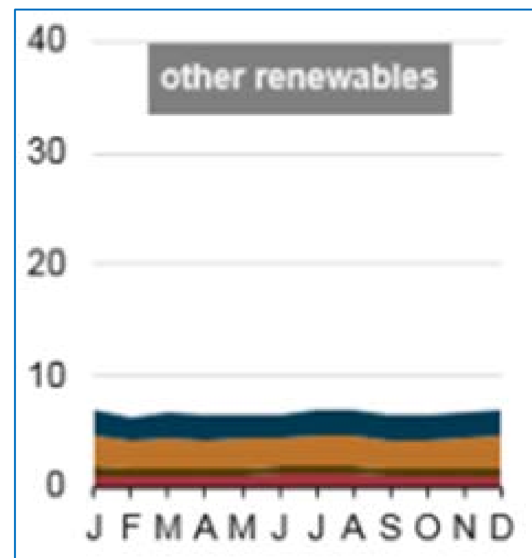
Monthly Renewable Electricity Generation by Census Region, 2017 (GWh)











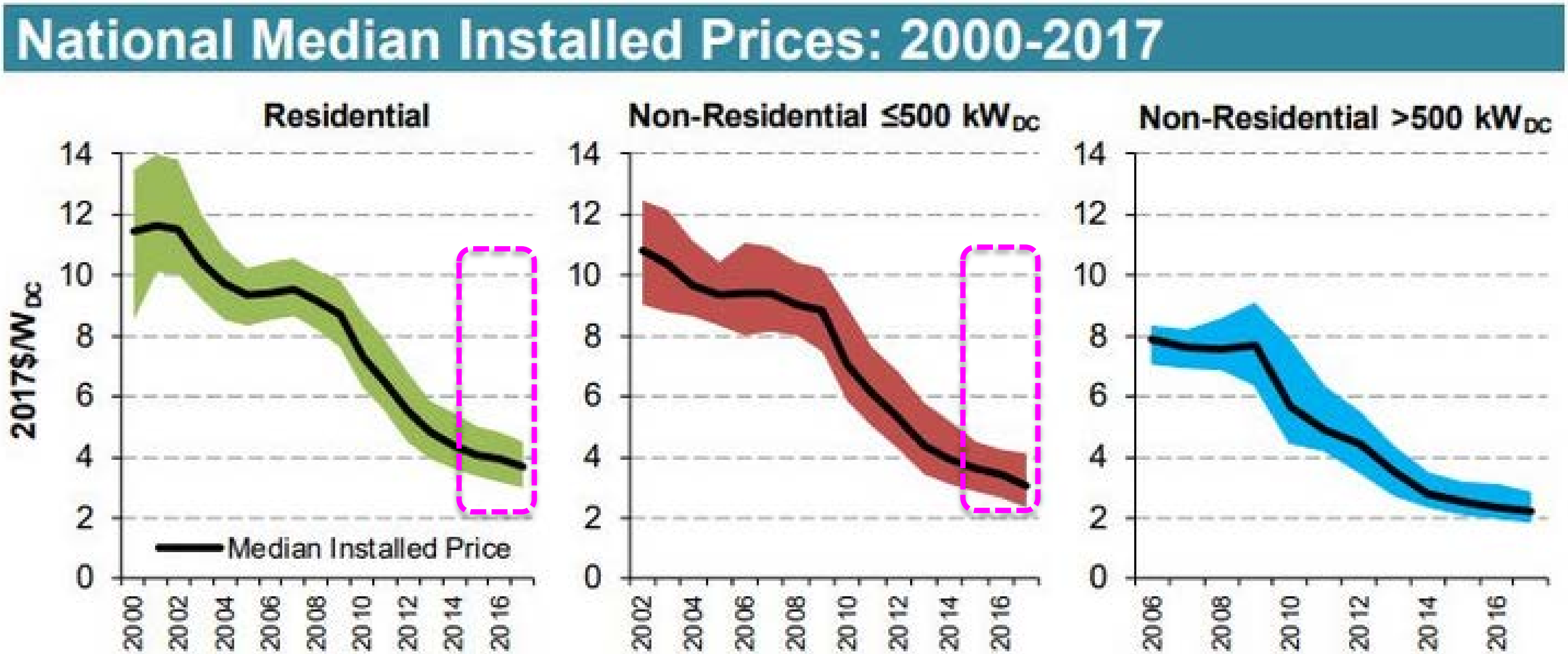
Source: https://www.nrel.gov/docs/fy18osti/70917.pdf [Source: EIA, Today in Energy, January 10, 2018. https://www.eia.gov/todayinenergy/detail.php?id=34472]

Solar Energy Overview

Market Trends
Solar Resource
PV Basics

Installed Costs of PV – Dramatic Decline

SOLAR

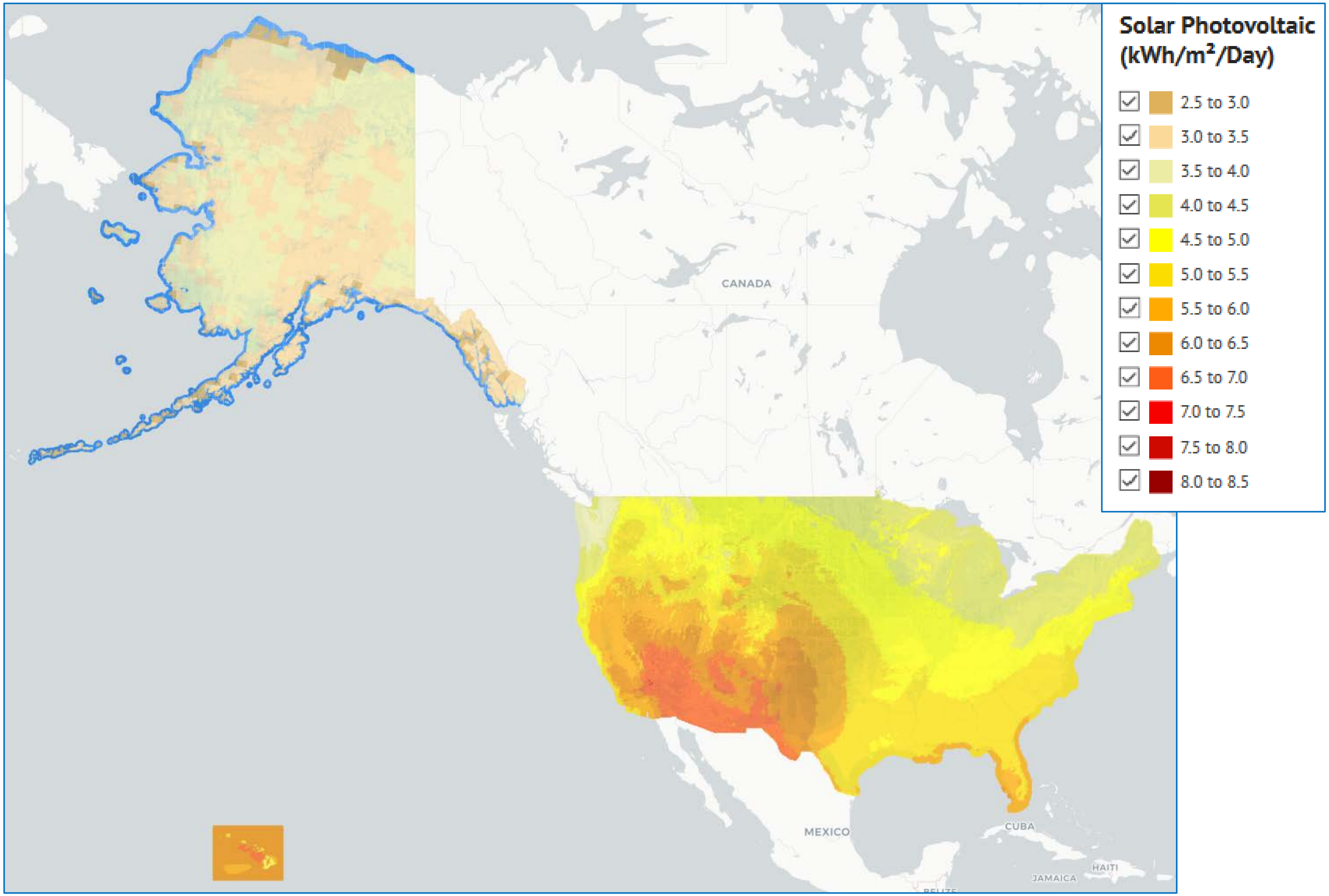


Notes: Solid lines represent median prices, while shaded areas show 20th-to-80th percentile range. Summary statistics shown only if at least 20 observations are available for a given year and customer segment.

In all sectors, there is a very sharp decline in price from 2009-2014.
There is still declines into 2017.
Through the first half of 2018, there was another $0.10/Watt price decline in residential and small-nonresidential PV systems.

NREL – Solar – RE Atlas

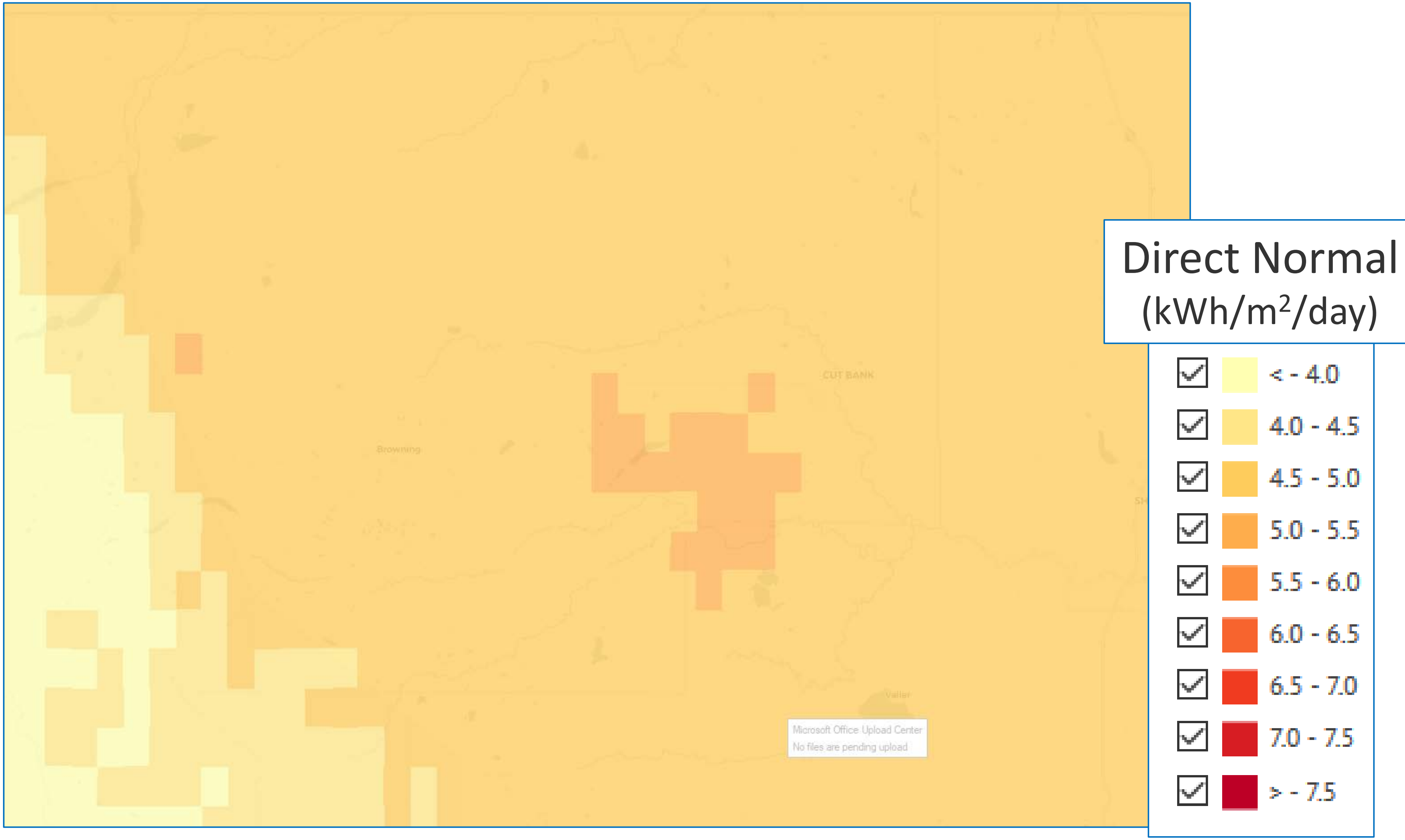
SOLAR



Source: https://maps.nrel.gov/re-atlas/

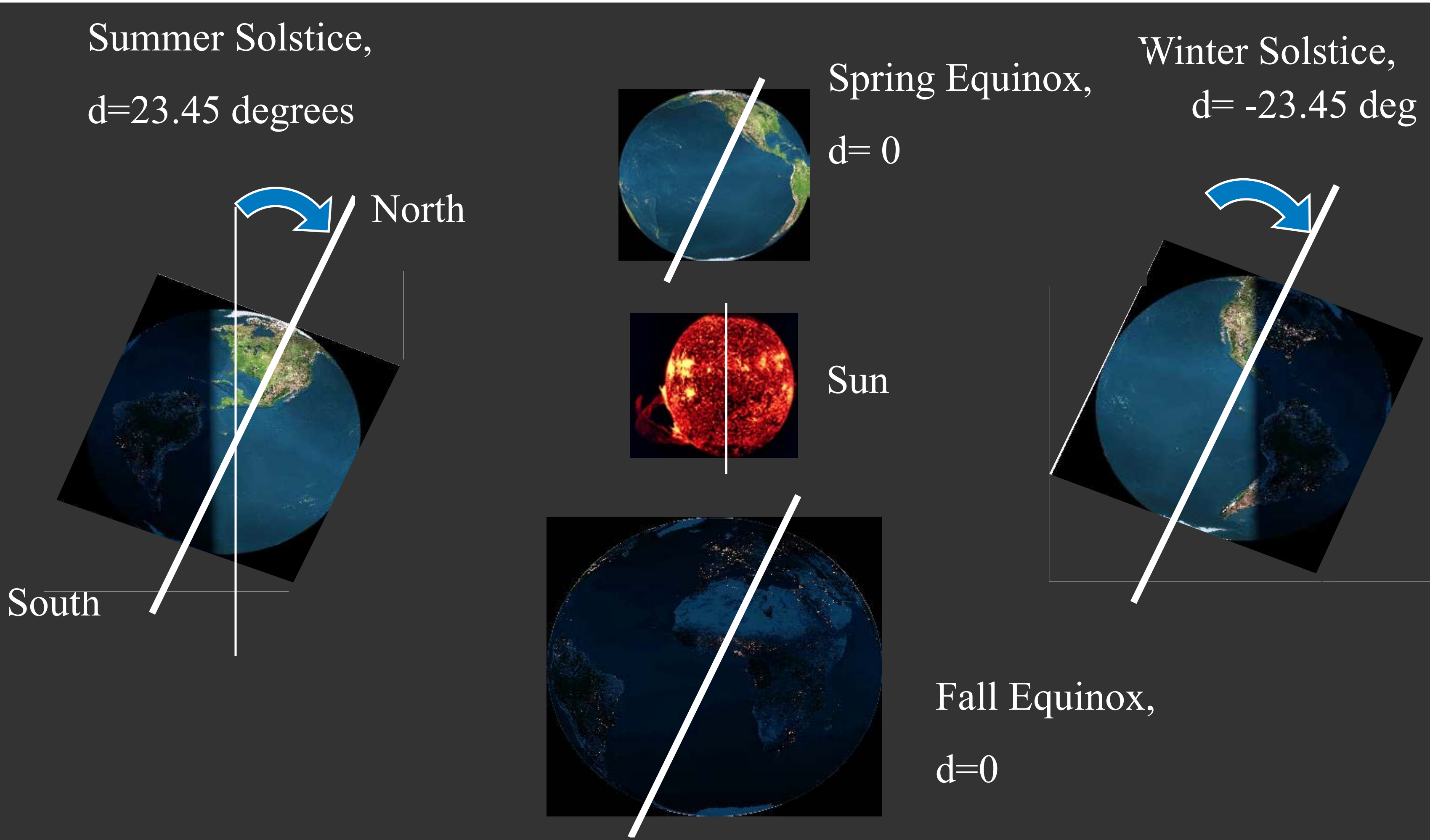
NREL – Solar – RE Atlas

SOLAR



Static maps can be found at: https://www.nrel.gov/gis/solar.html

Declination, d, and the Seasons

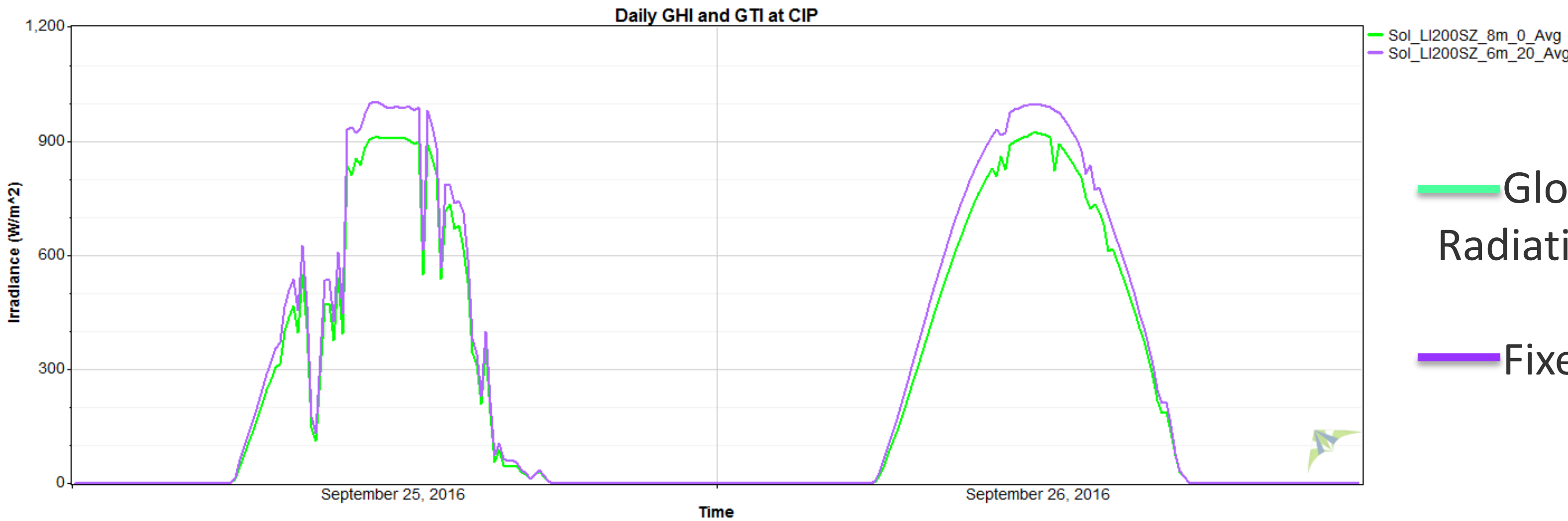


$$d = 23.45 \cos (2 \pi / 365 (i - 172))$$

Julian day of the year = i = 1 - 365

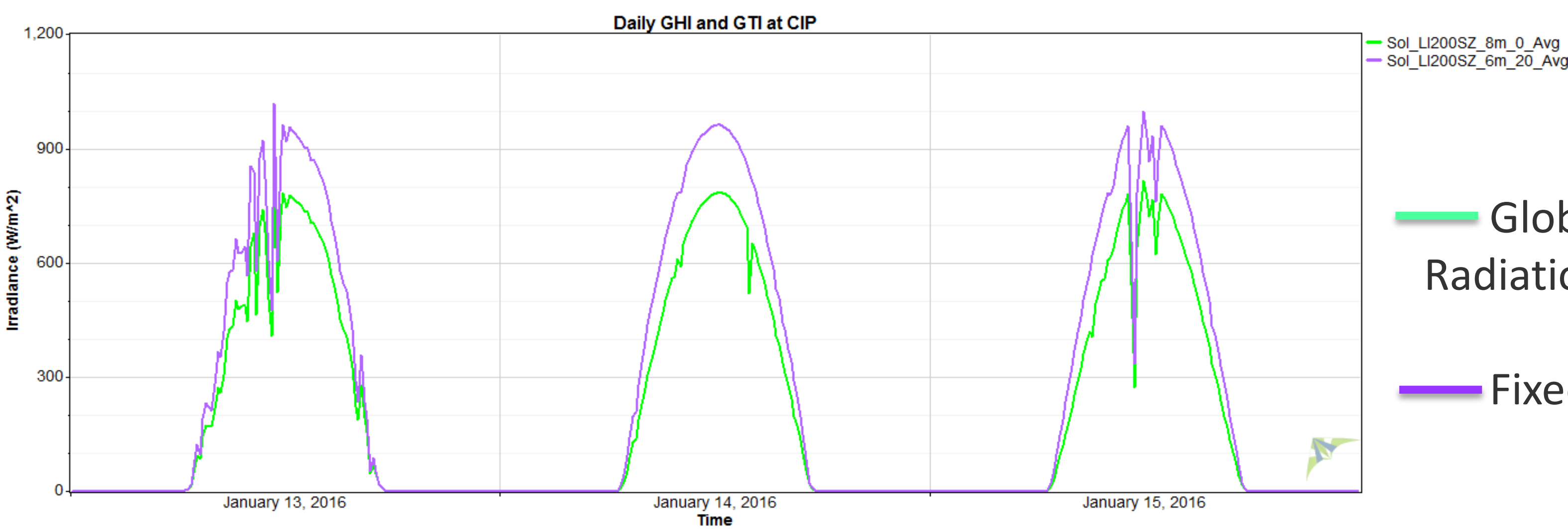
Typical Solar Radiation Fluctuations

SOLAR



Global Horizontal Radiation

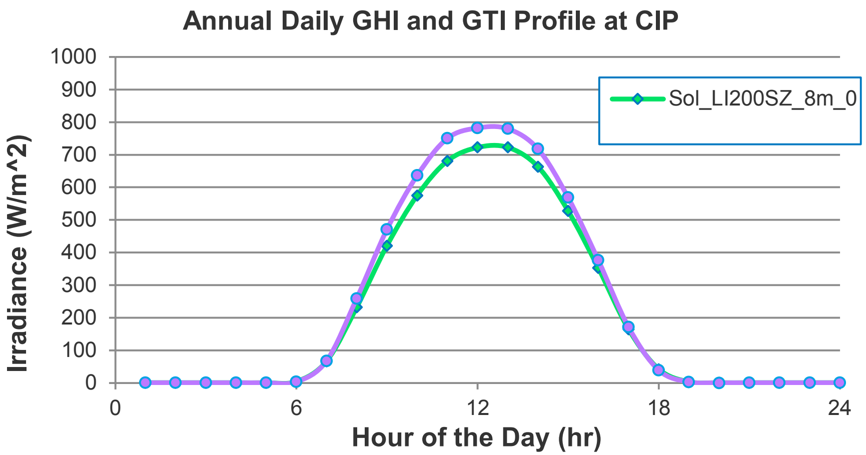
Fixed Tilt Radiation



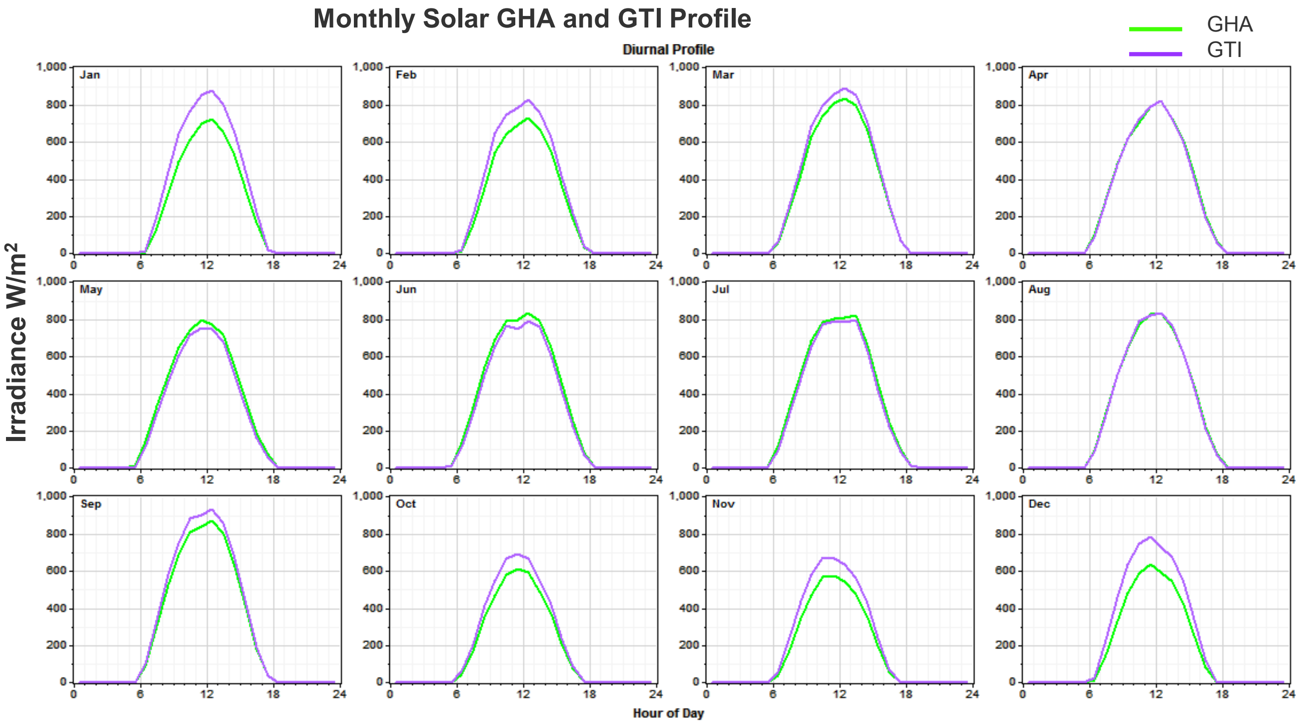
Global Horizontal Radiation

Fixed Tilt Radiation

Annual & Monthly Solar Profile “Smooths”



Annual Solar Resource – sun never shines at night

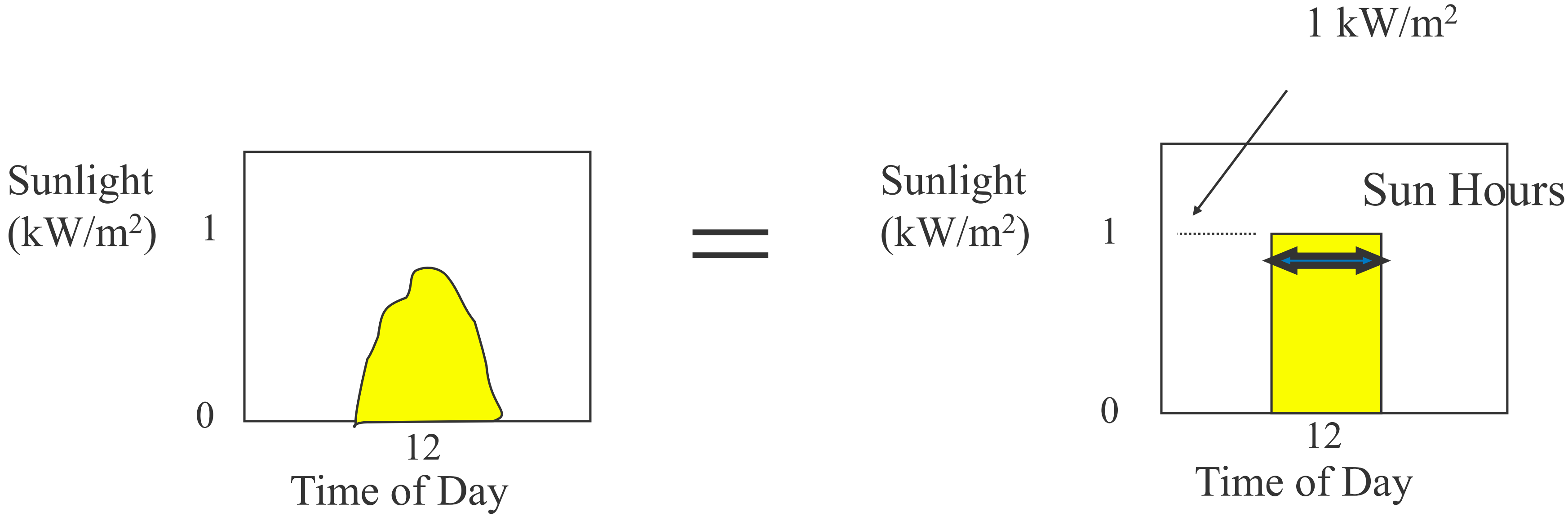


Monthly Solar Resource – summer months much better than winter months

Definition of "Sun Hours"

SOLAR

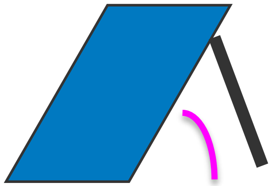
"Rated Power" is the output of a PV module under standard reference conditions
(1 kW/m^2 light, 25 C, 1 m/s wind speed).



Example: July in Annapolis 4.5 kWh/m^2/day = 4.5 "sun hours"/day A module "rated" at 1 kW would produce 4.5 kWh in that day.

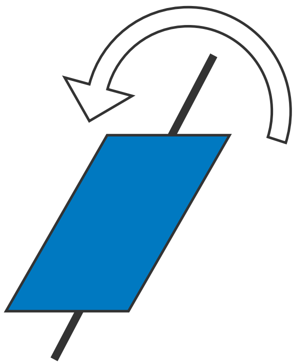
Fixed Tilt and Tracking

SOLAR

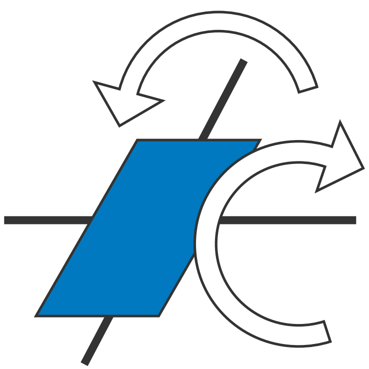


Fixed Tilt Facing Equator

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



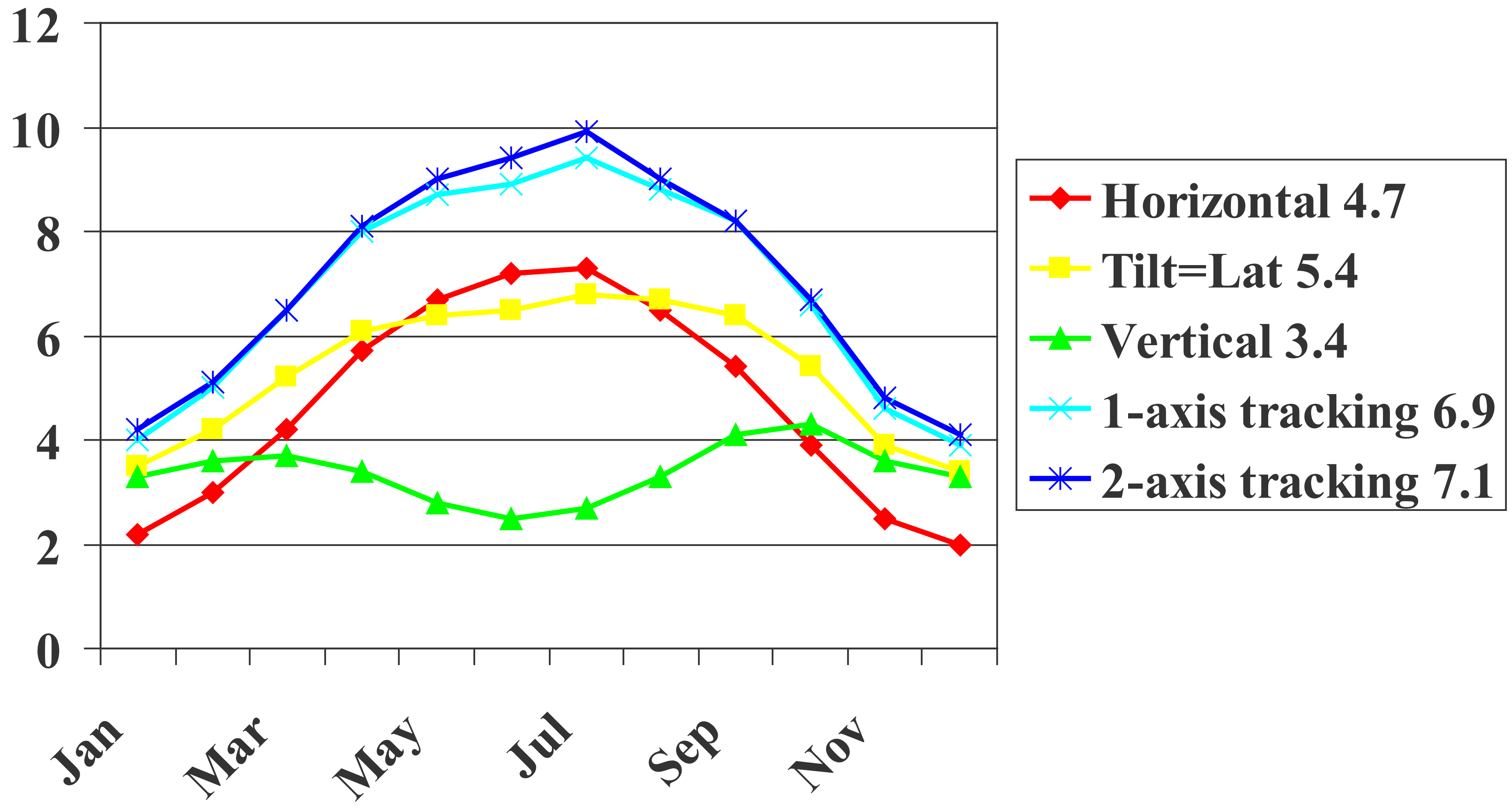
One Axis Tracking around axis tilted or flat



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

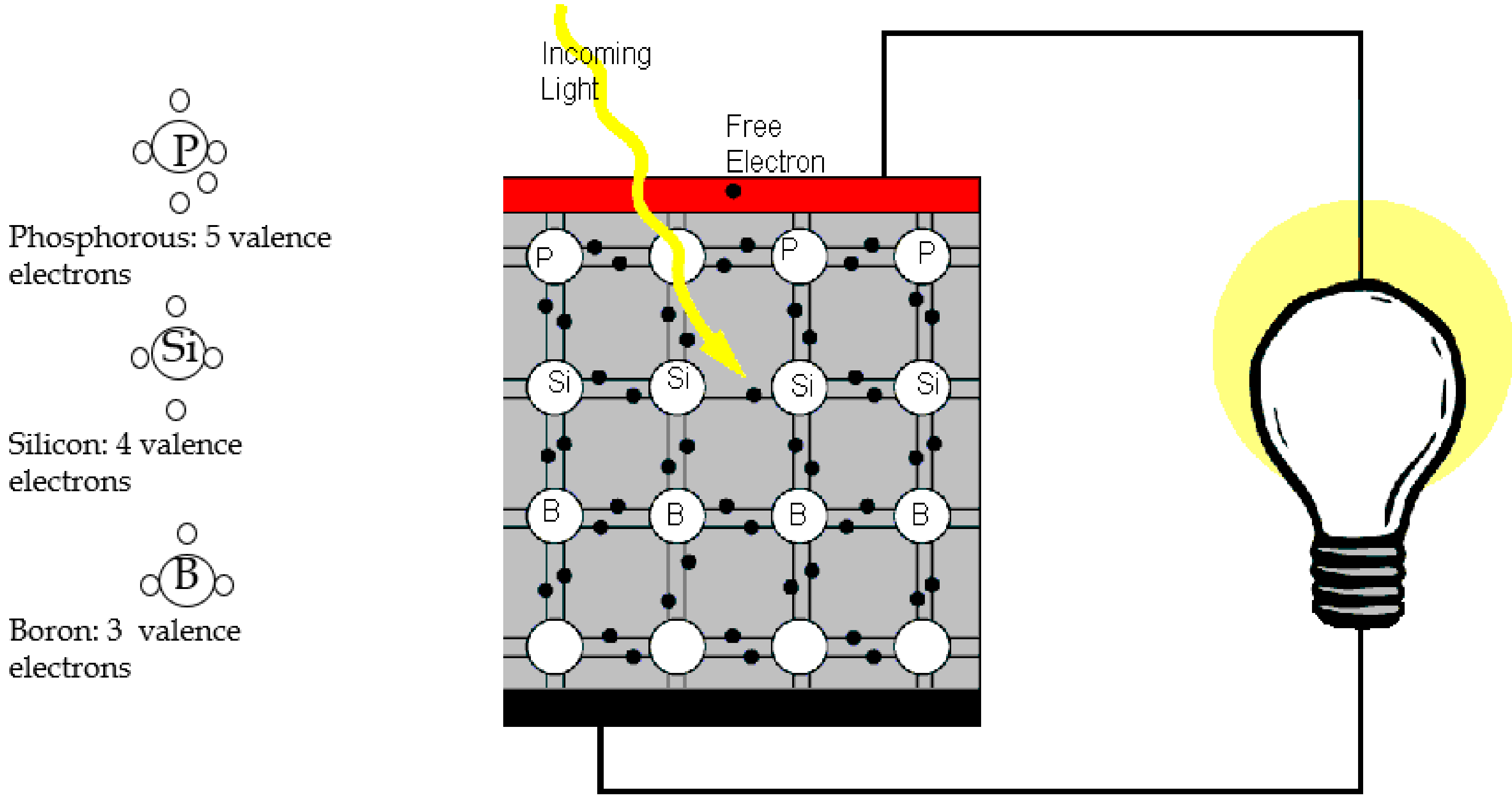
Effect of Orientation

Average daily solar radiation (kWh/m²/day)



The Photovoltaic Effect

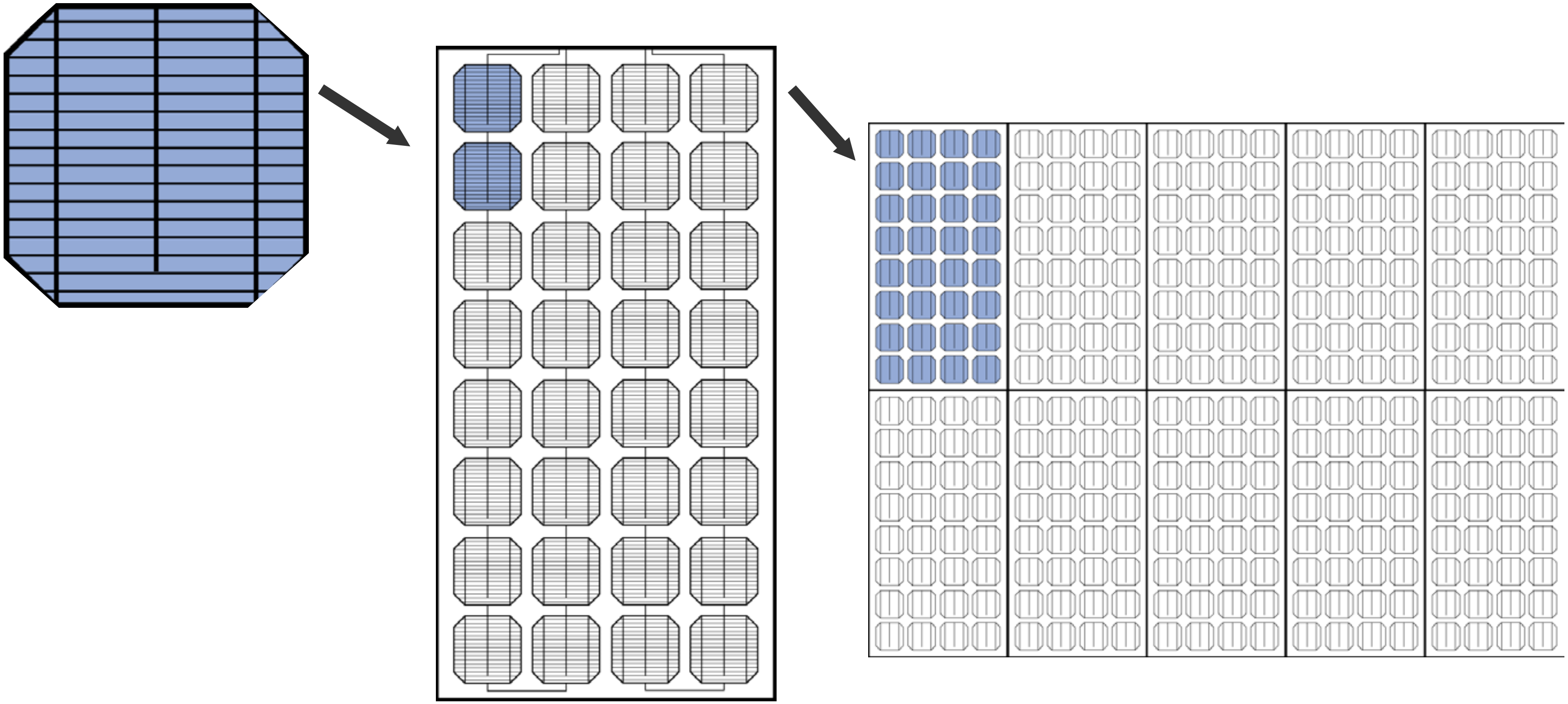
SOLAR



No material is consumed and the process could continue indefinitely.

AND, there are NO MOVING PARTS, only moving electrons!

PV is Modular – Build System to Size Needed



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

Federal Incentives

Financial Incentives - Tax Credit Applied Against Federal Income Tax:

- Investment Tax Credit (ITC) is available through 12/31/2019 at 30%
    - Ratchets down to 26% (2020) , 20% (2021) , the 10% (2022) into the future
- Applies to solar, wind, biomass (CHP) and other renewable technologies

Federal Modified Accelerated Cost-Recovery System (MACRS):

- 100% depreciation in 5 years
- Applies to solar, wind, biomass and other renewable technologies
- Period: 9/17/2017 – 1/1/2023

Source: DSIRE web site: http://www.dsireusa.org//

Tribal 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 Norther 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

NREL – PV WATTS

SOLAR

Source: https://pvwatts.nrel.gov/

NREL – PV WATTS

Location and Station Identification

Requested Location	main st, Browning MT
Weather Data Source	(TMY2) CUT BANK, MT 30 mi
Latitude	48.6° N
Longitude	112.37° W

PV System Specifications *(Commercial)*

DC System Size	10000 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	45°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Economics

Average Cost of Electricity Purchased from Utility	0.08 $/kWh

Performance Metrics

Capacity Factor	16.9%

NREL – PV WATTS

SOLAR

RESULTS

Print Results

14,834,017 kWh/Year*

System output may range from 14,061,165 to 15,016,475kWh per year near this location. Click HERE for more information.

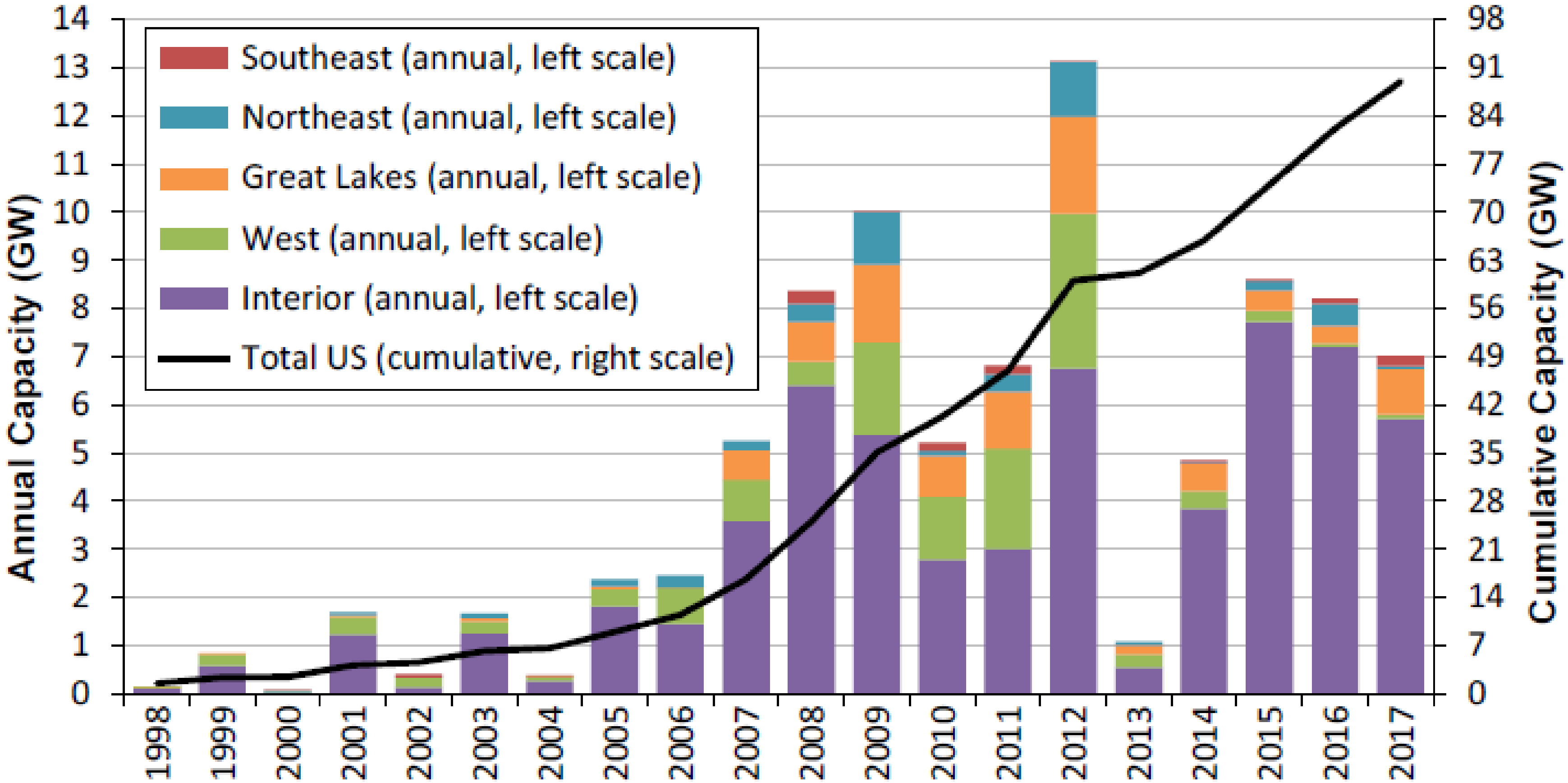
Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value ($)
January	3.26	898,183	67,454
February	4.28	1,050,297	78,877
March	5.08	1,350,852	101,449
April	5.36	1,319,726	99,111
May	5.84	1,455,527	109,310
June	6.07	1,455,714	109,324
July	6.89	1,638,528	123,053
August	6.37	1,525,982	114,601
September	5.39	1,308,430	98,263
October	4.78	1,225,871	92,063
November	3.27	846,891	63,602
December	2.73	758,015	56,927
Annual	**4.94**	**14,834,016**	**$ 1,114,034**

Wind Energy Overview

Wind Market Trends
Wind Costs

Key Factors
Wind Assessment
Sample Project

Turbine Installations by Region – Annual & Cumulative

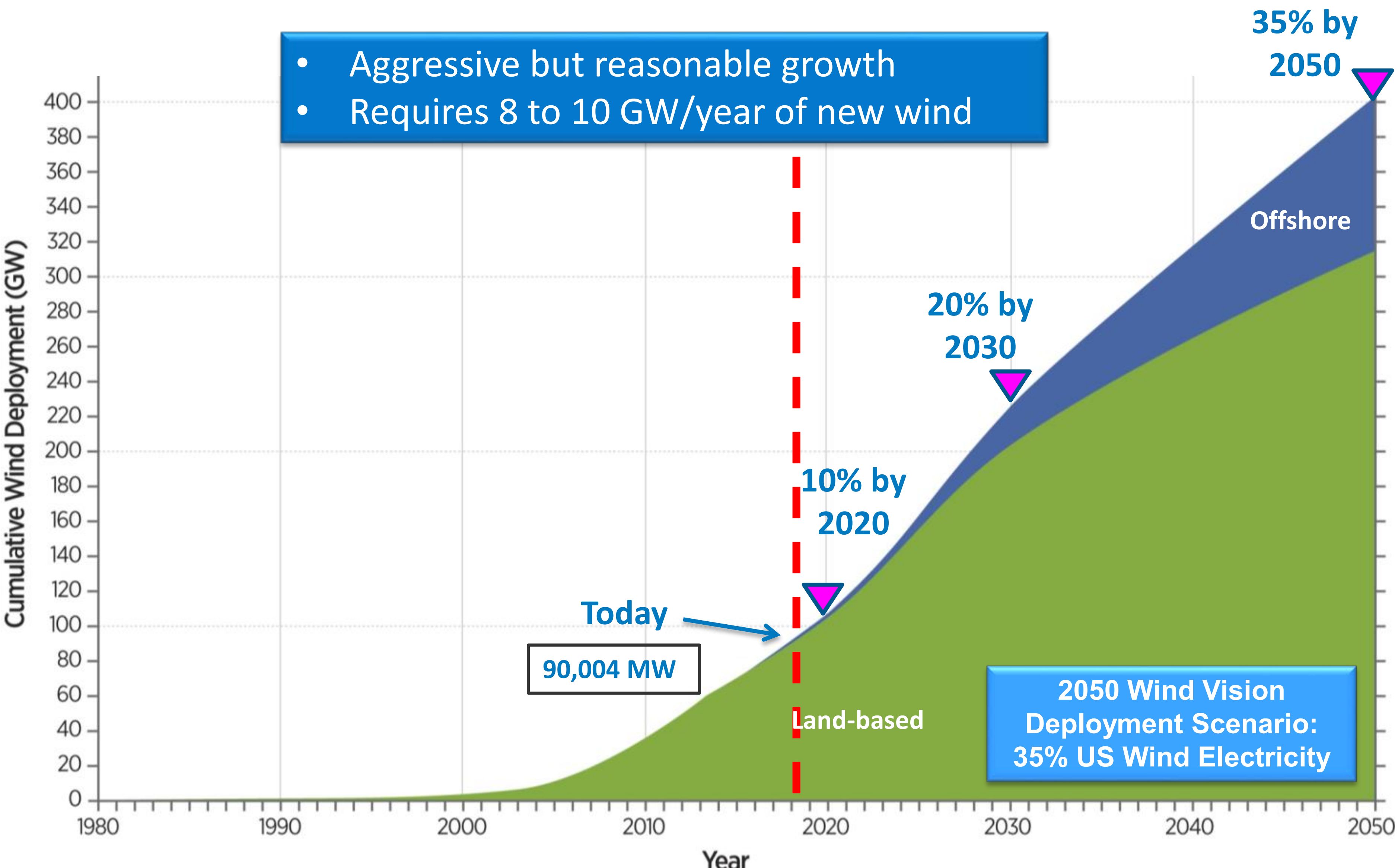


Source: AWEA WindIQ

Figure 2. Annual and cumulative growth in U.S. wind power capacity

Policy has been an important driver:
Production Tax Credit (PTC)
Investment Tax Credit (ITC)
Accelerated Depreciation (MACRS)
Renewable Portfolio Standards (RPS)

Longer View ➡ Implement U.S. Wind Vision to Enable Wind Power Nationwide



Ref: DOE Wind Vision Report: http://energy.gov/eere/wind/wind-vision

Wind Technology Changes Over 20 Years

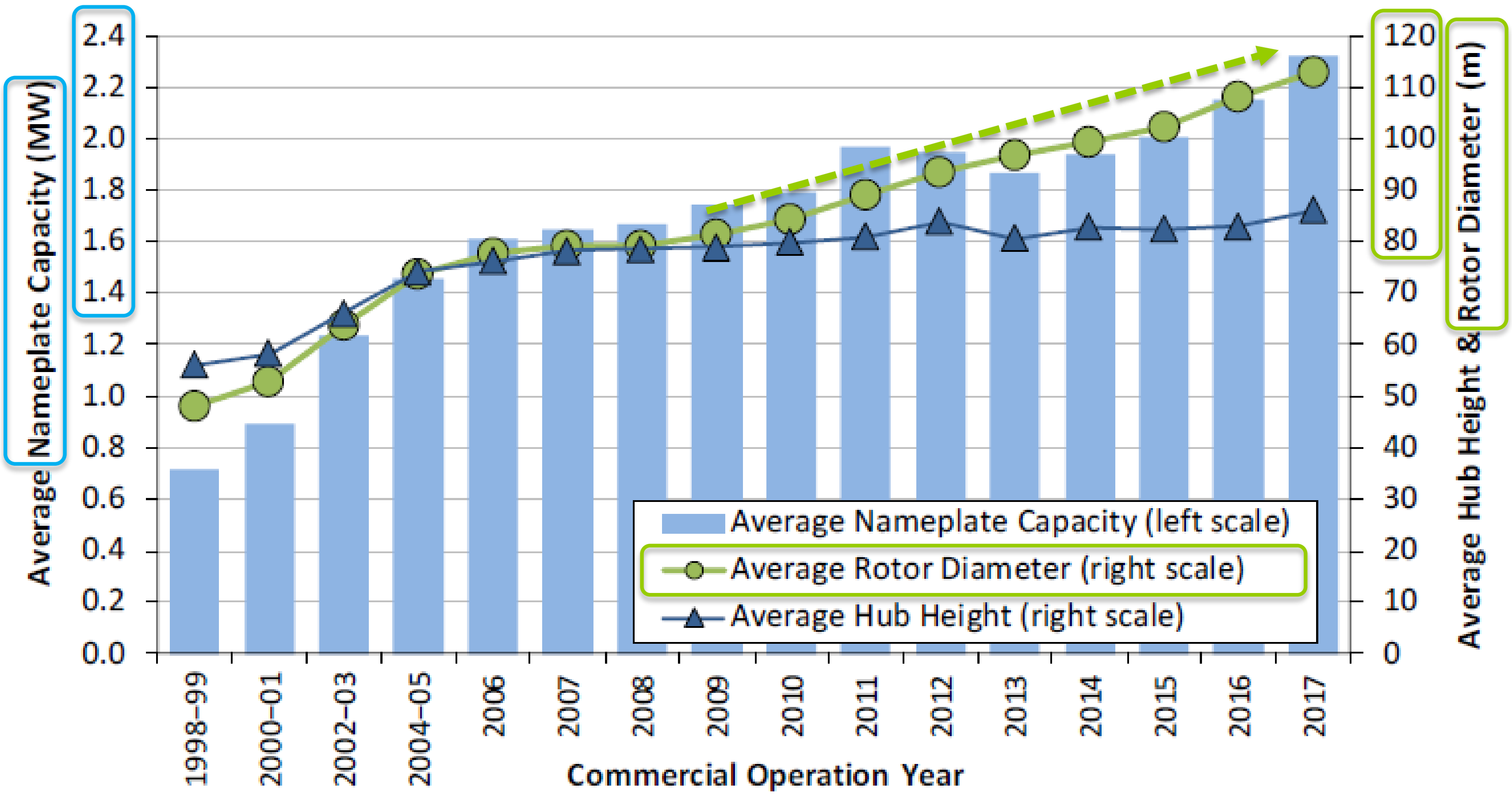


Figure 20. Average turbine nameplate capacity, rotor diameter, and hub height for land-based wind projects[35]

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

Distributed Wind - Incentives

Federal Modified Accelerated Cost-Recovery System (MACRS):

- 100% depreciation in 5 years
- Applies to wind, solar, biomass and other renewable technologies
- Period: 9/17/2017 – 1/1/2023

Financial Incentives - Tax Credit Applied Against Federal Income Tax:

- Wind turbines up to 100 kW are eligible for the 30% federal Business Energy Investment Tax Credit (ITC) through 2018 at $4,000. After 12/31/2018 there is no limit.
- Production Tax Credit (PTC) is available through 12/31/2019
  - 2018: $0.0138/kWh for first 10 years
  - 2019: $0.0092/kWh for first 10 years

Source: DSIRE web site: http://www.dsireusa.org//

Installed Cost Range by Project Size

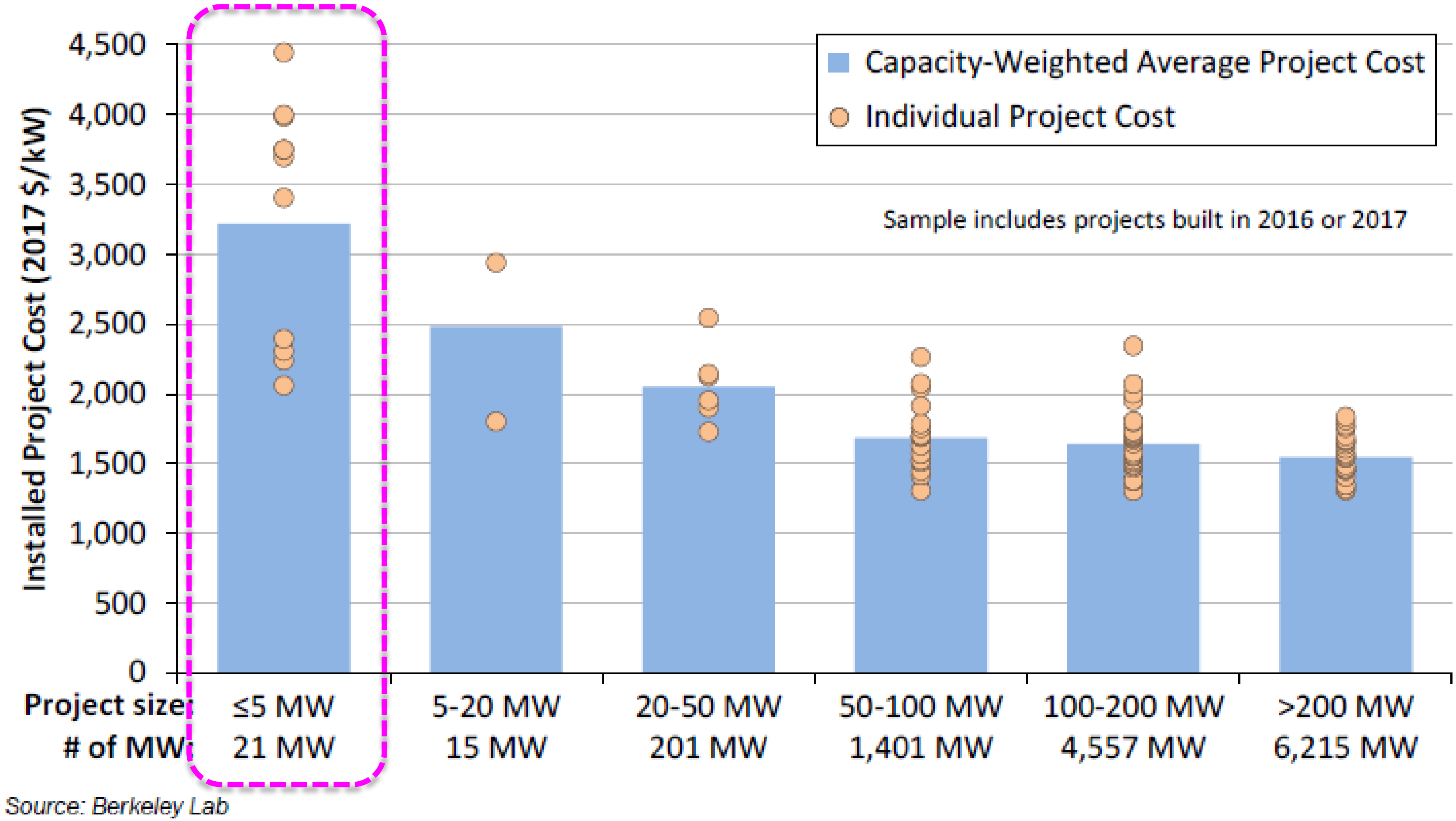


Figure 44. Installed wind power project costs by project size: 2016–2017 projects

- 1-2 utility-scale turbine projects are MUCH MORE COSTLY PER TURBINE than 100MW⁺ wind farms

Distributed Wind – 2017 Market Report

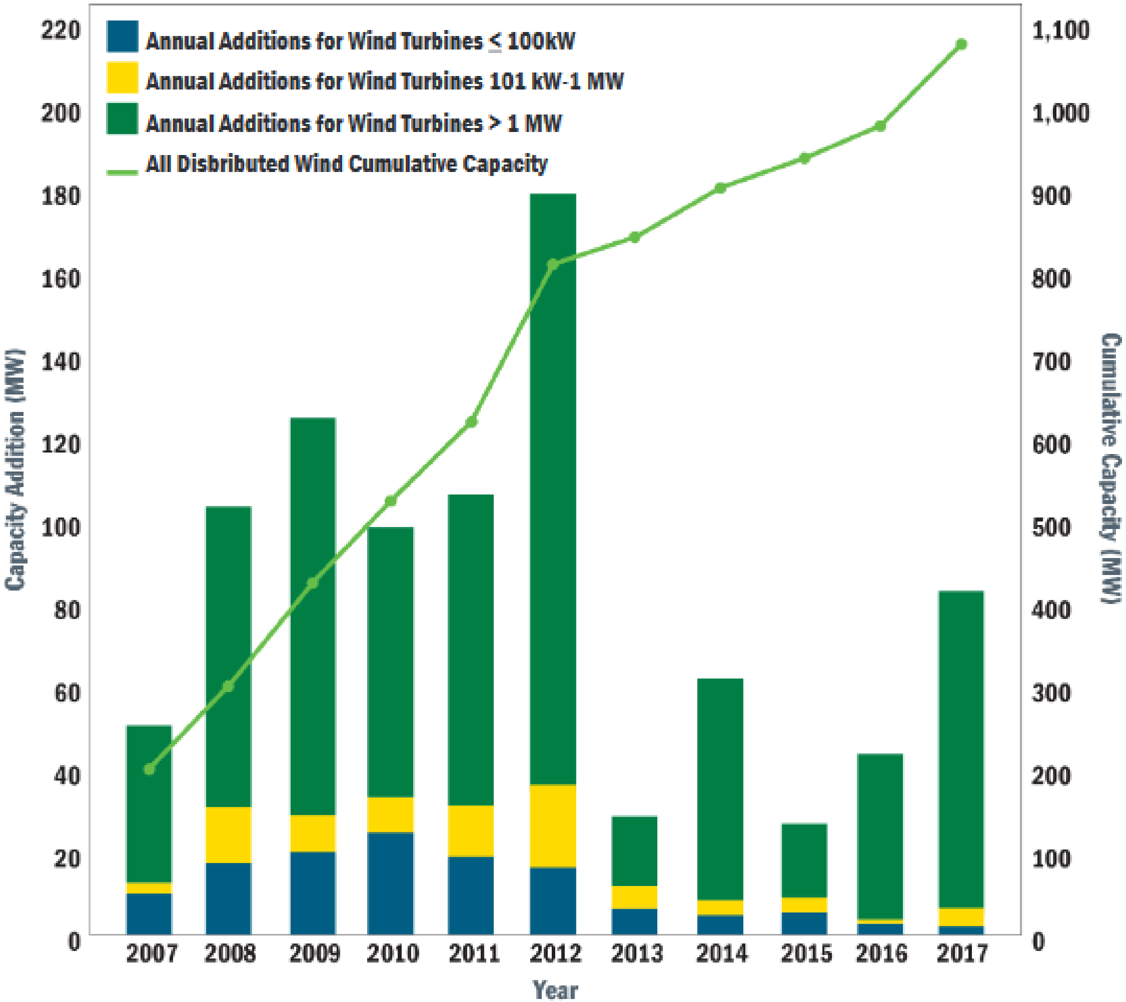


Figure 1. U.S. distributed wind capacity

Over the last decade, 1-2 utility-scale turbine installations have become the most common 'distributed' wind application

Distributed scale:

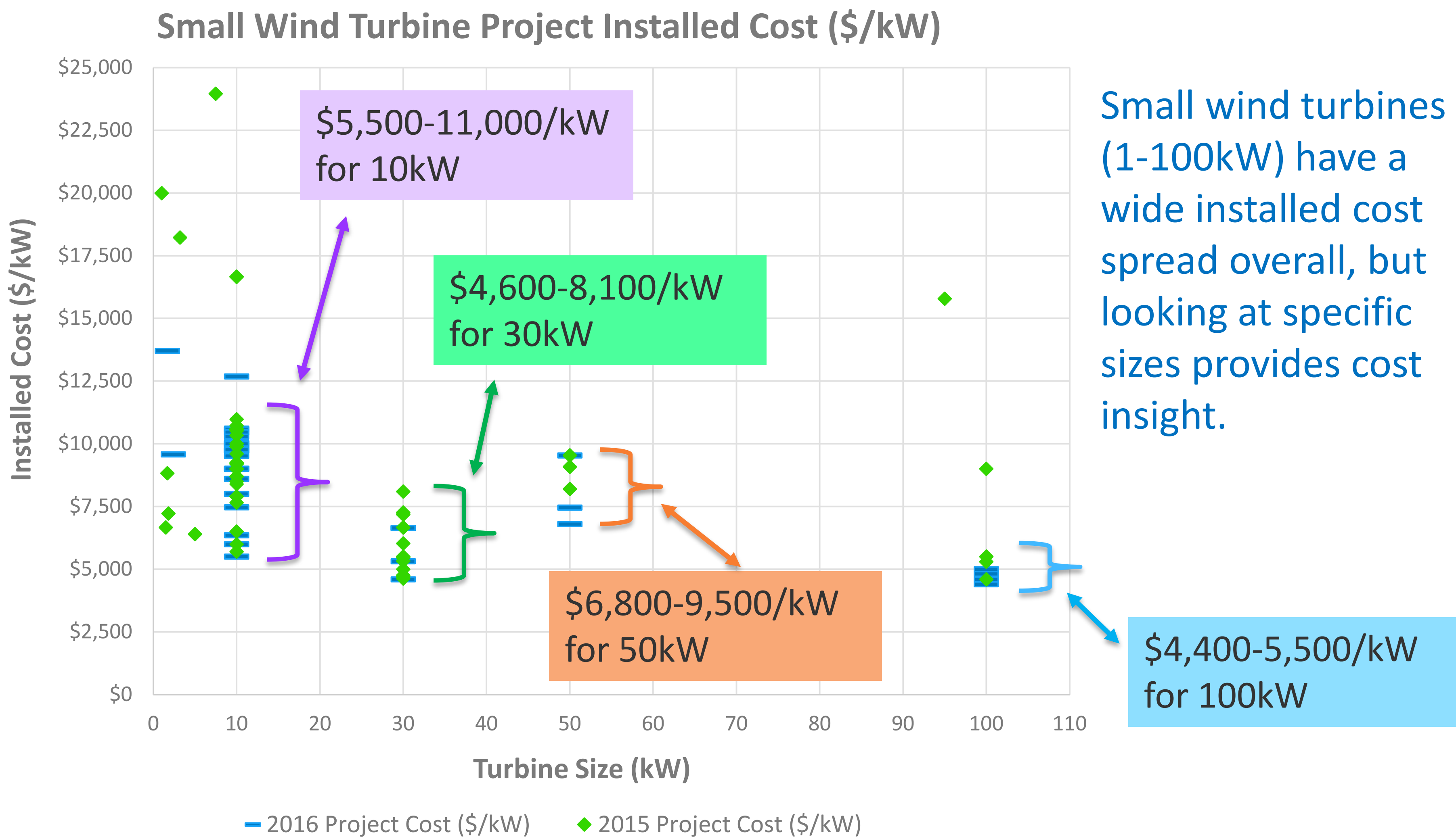
1,000 MW → 81,000 turbines

Utility-scale wind:

91,000 MW → 54,000 turbines

Source: https://www.energy.gov/eere/wind/2017-wind-market-reports#distributed

Small Wind – Installed Cost Range by Size



Small wind turbines (1-100kW) have a wide installed cost spread overall, but looking at specific sizes provides cost insight.

How much electricity turbines make annually depend on the wind speeds and distribution

Source: https://www.energy.gov/sites/prod/files/2017/08/f35/2016-Distributed-Wind-Market-Report.pdf and https://www.energy.gov/sites/prod/files/2016/08/f33/2015-Distributed-Wind-Market-Report-08162016_0.pdf

Wind Resource – Useful Characteristics to Know

Mean wind speed – average annual wind speed
[Is this a windy location?]

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

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

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 – Useful Characteristics to Know

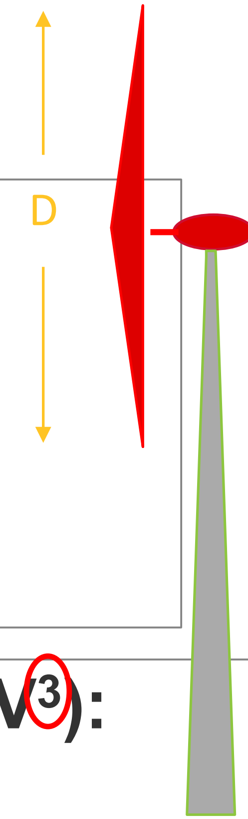
Seasonal wind distribution – how many months/what time of year has the strongest wind?
[When I can generate most cheaply, when to I need it most, how does it compare to solar and hydro? And the load? When do loads peak?]

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?]

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

Power in Wind Equation

Wind energy is kinetic energy – mass and momentum



Derived from K.E. = ½ mv^2

$$P = A * \rho * V^3/2$$

- P = Power of the wind [Watts]
- A = Windswept area of rotor (blades) = $\pi D/4 = \pi r^2$ [m^2]
- ρ = Density of the air [kg/m^3] (at sea level at 15°C)
- V = Velocity of the wind [m/s]

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

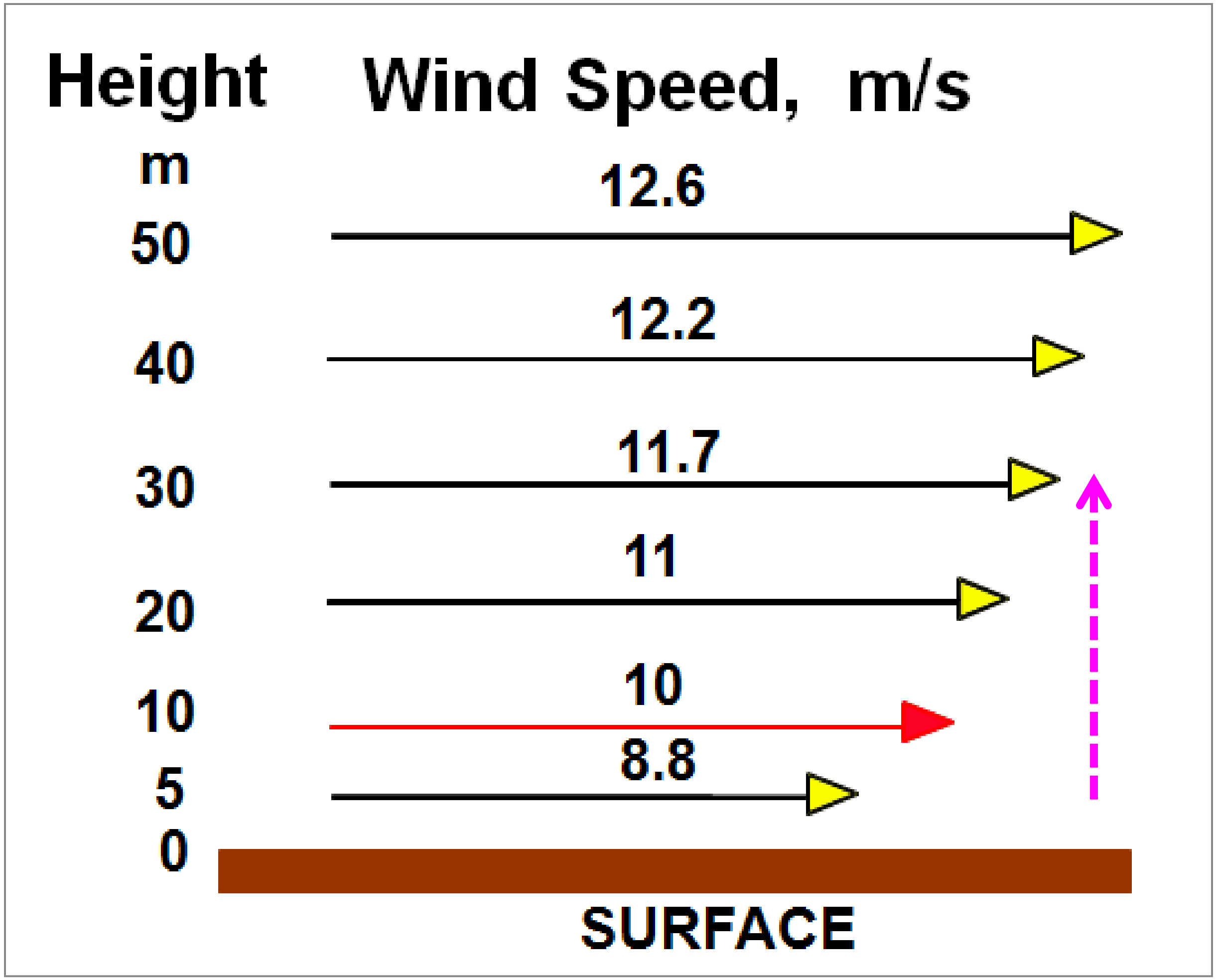
– 25% higher wind speed ≈ **2 times the power** available

–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!

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

Wind Primer – Wind Shear

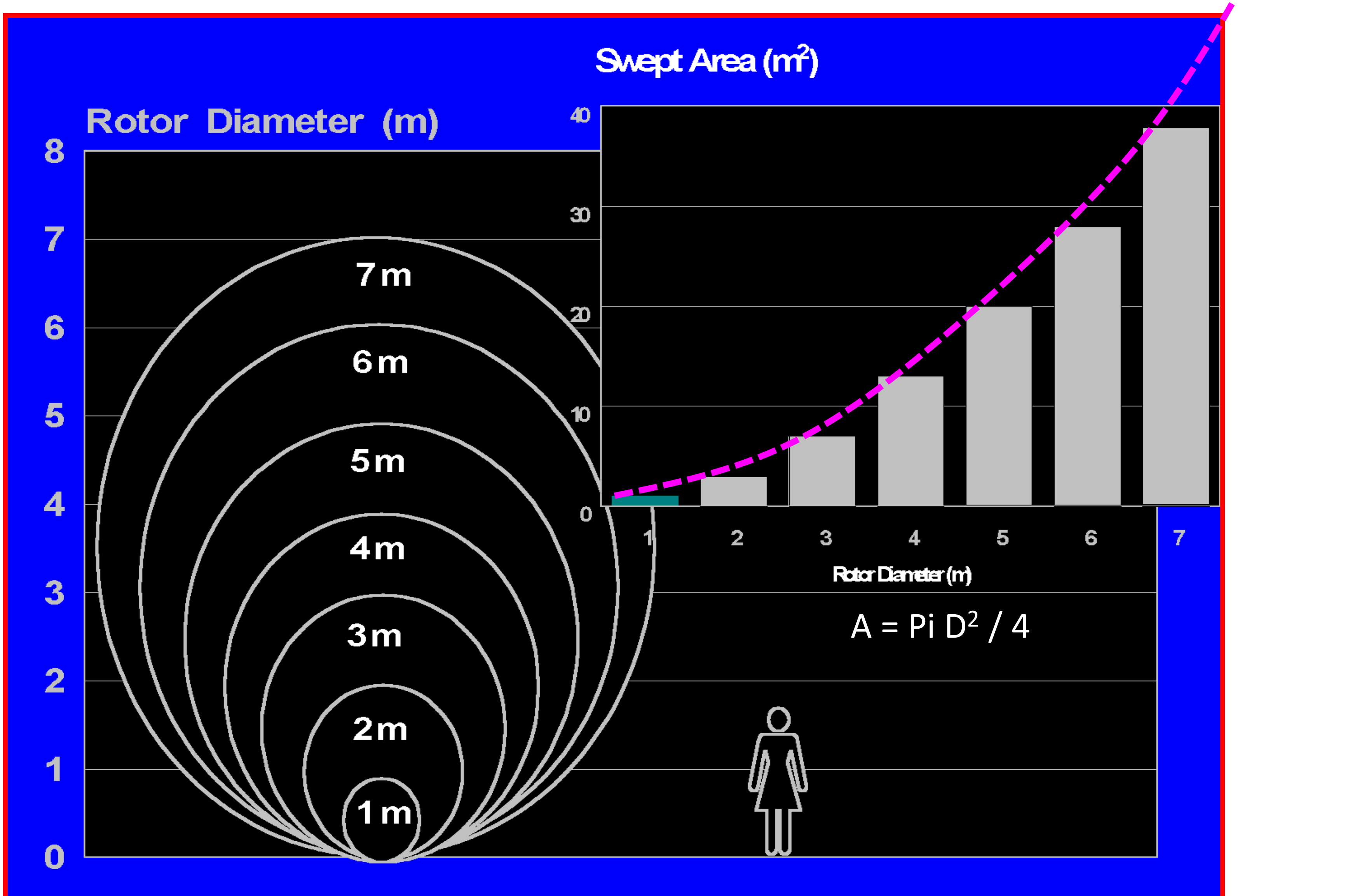


Increasing the wind speed from 8.8 to 11 m/s (25% increase), doubles the available power in the wind!

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

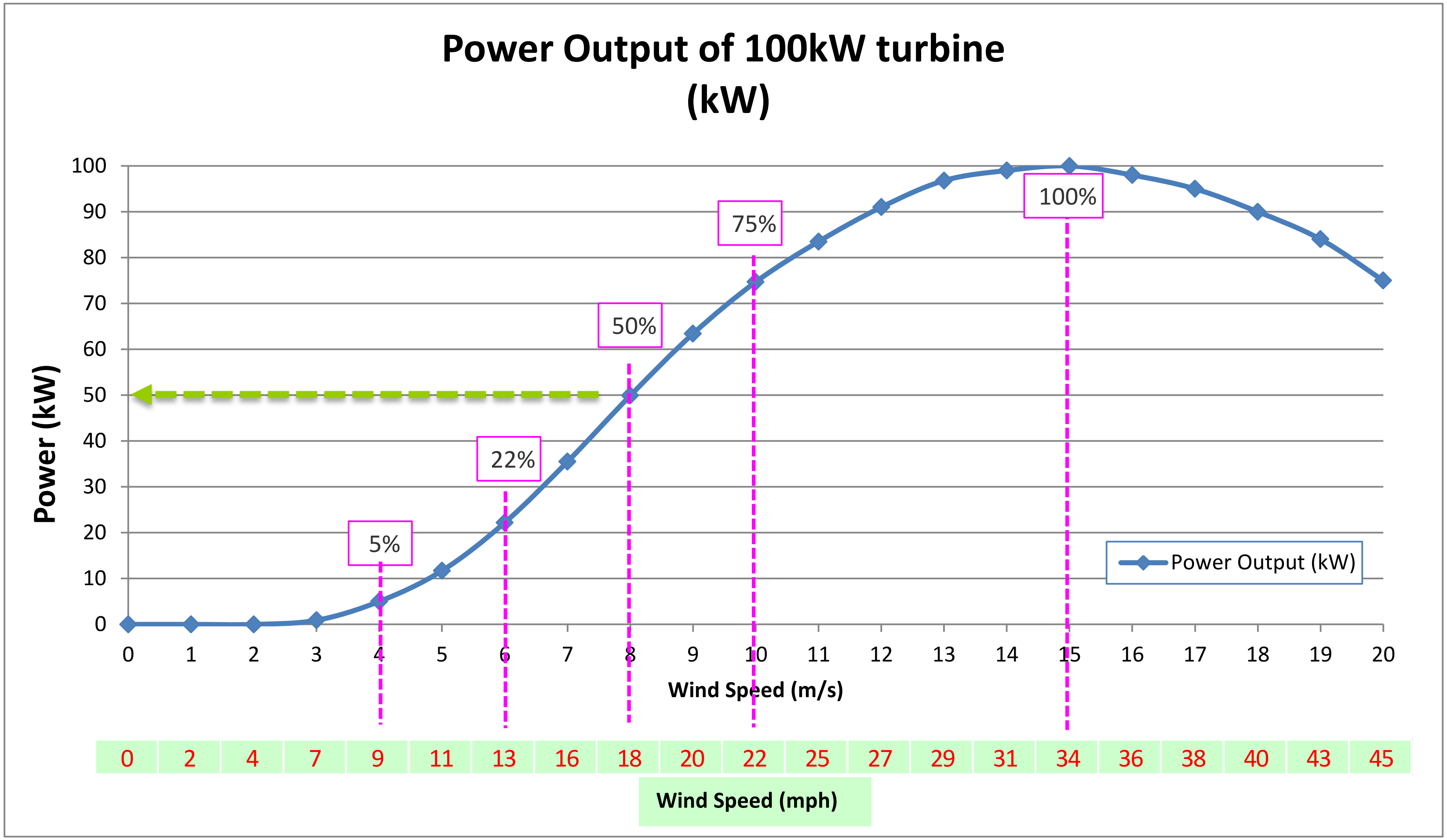
Courtesy of Alternative Energy Institute

Relative Size of Small Wind Turbines



Credit: Paul Gipe

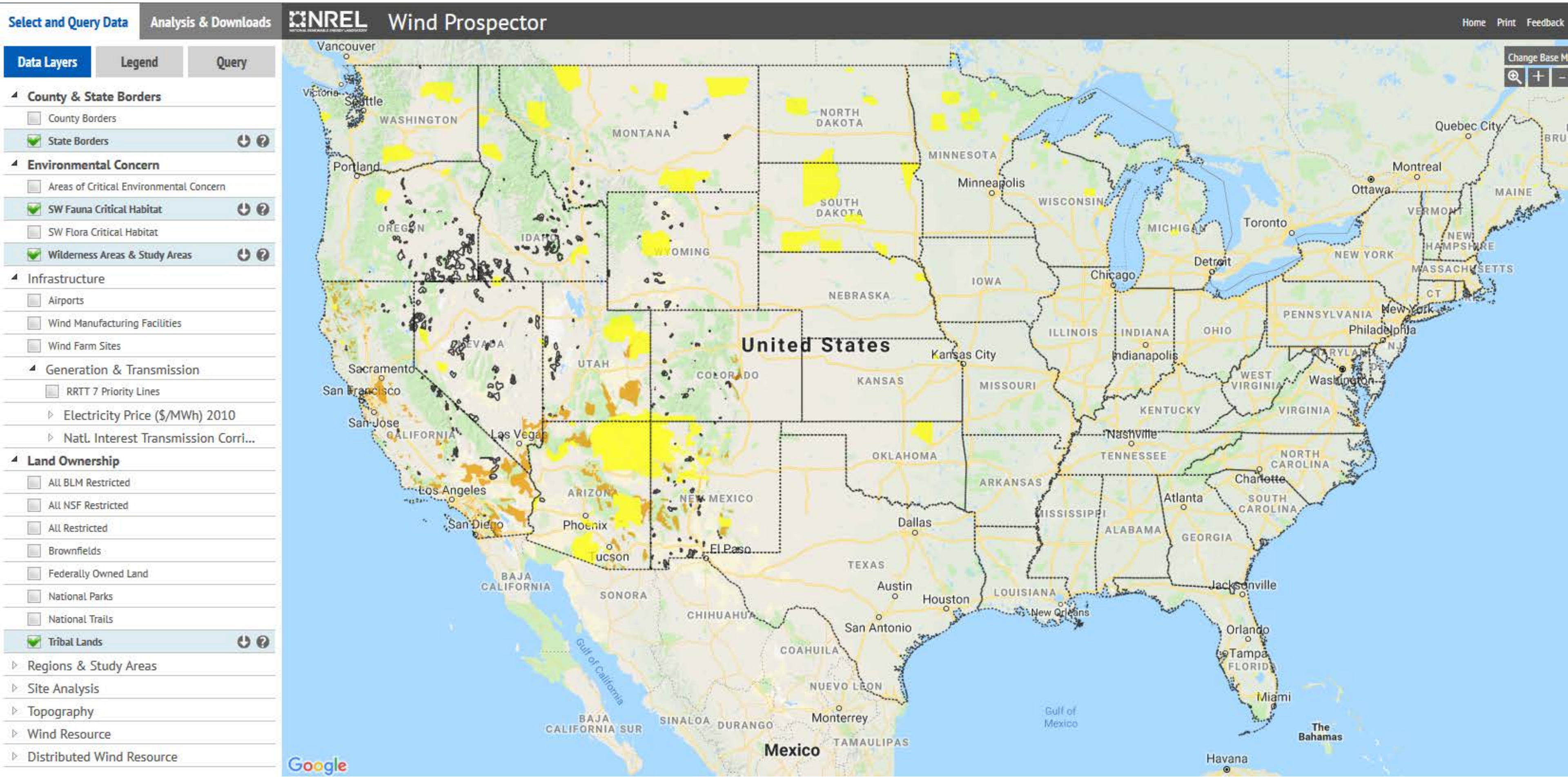
Wind Primer – Power Curves



A 100 kW wind turbine does NOT produce 100 kW when it is "spinning." The average wind speed at Site A at 30m (100 ft) is 6.0 m/s (13.4 mph). It will produce 22kW at that speed.

Turbines are purchased for how much energy they produce annually, not for their rated power.

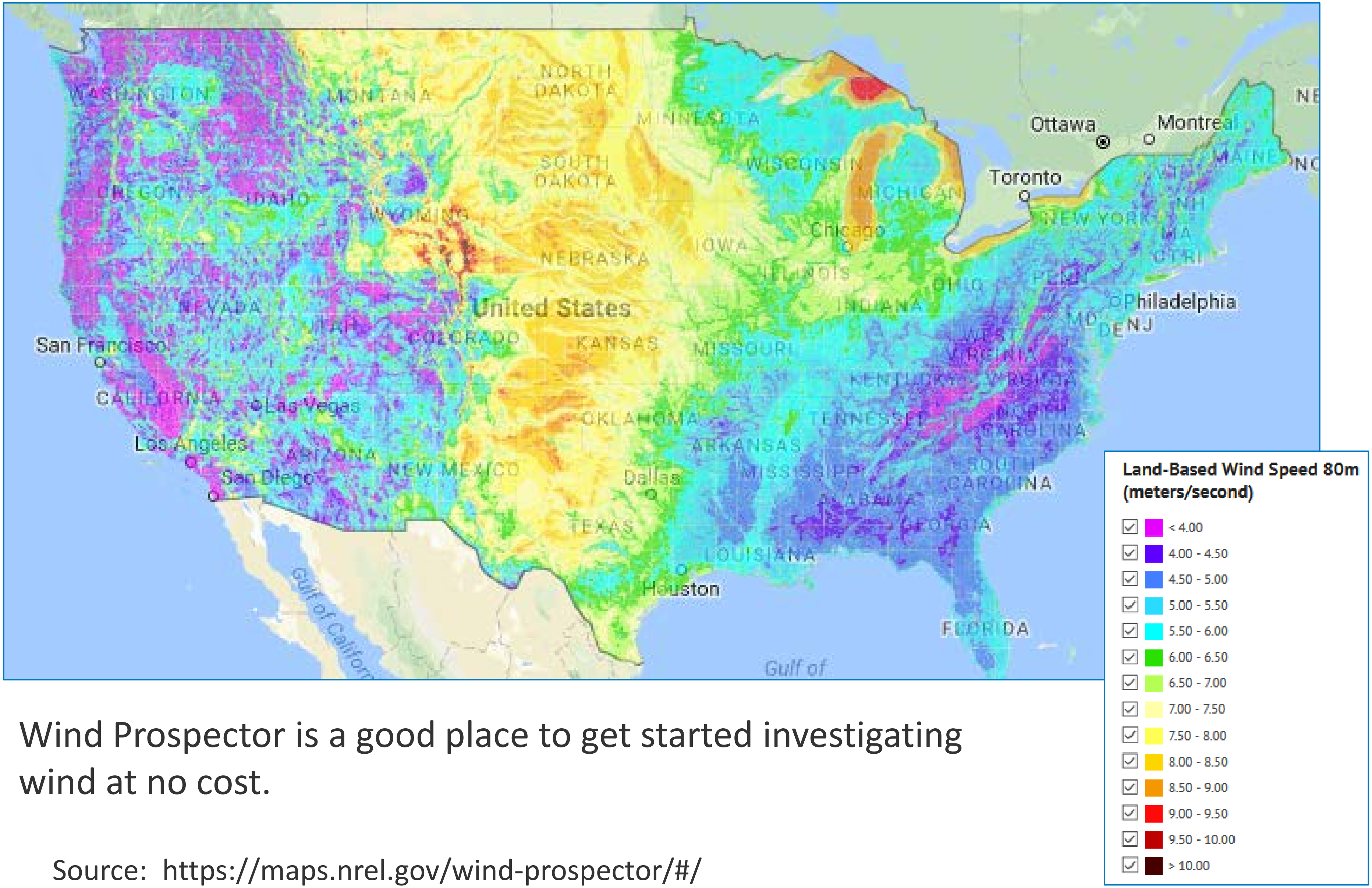
NREL – Wind Prospector – Multi-factor Investigation



Many tabs on the left help to filter to the datasets of interest.

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

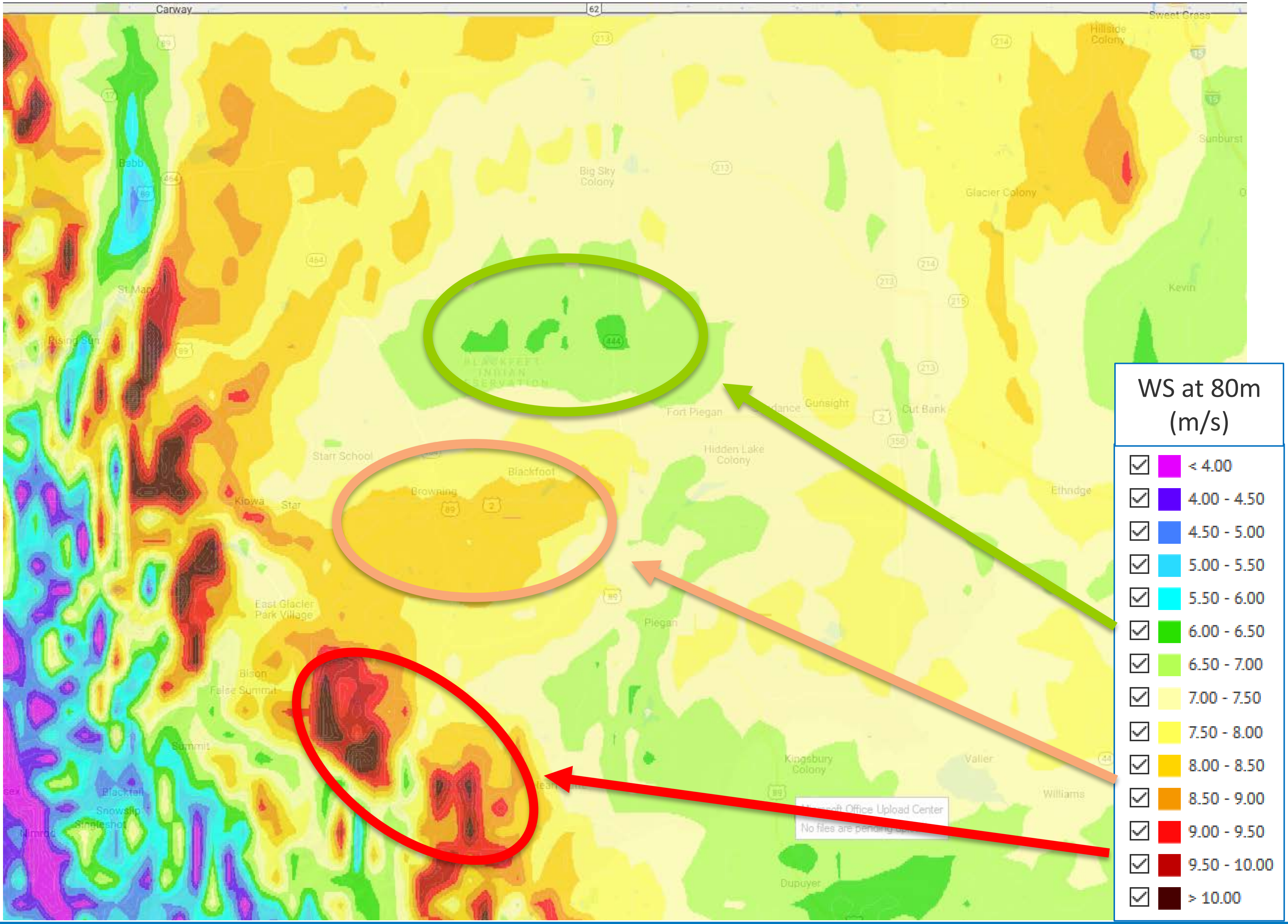
NREL – Wind Prospector



Wind Prospector is a good place to get started investigating wind at no cost.

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

NREL – Wind Prospector – Wind Speed



Seneca Nation of Indians – 1.7MW Wind Turbine

WIND 101

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

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