# Tribal Options Analysis Rules of Thumb: Solar, Wind, and Biomass

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# Community Benefits of Utility-Scale RE Development

## Economic

Renewable energy development creates multiple economic benefits to communities, including:

- Job creation (construction & permanent)
- Indirect impacts (employee spending at local businesses)

## Workforce Development

- Developers can agree to prioritize local, qualified labor for construction.
- Operations and maintenance work can often be carried out by locals.

## Land Lease Payments

- Land leases are a significant revenue stream for the life of the project, and are typically paid directly to the landowner.

## Community Funds

- Community funds may support energy efficiency, fire departments, schools, reduced electricity rates for low-income residents, etc.[1]

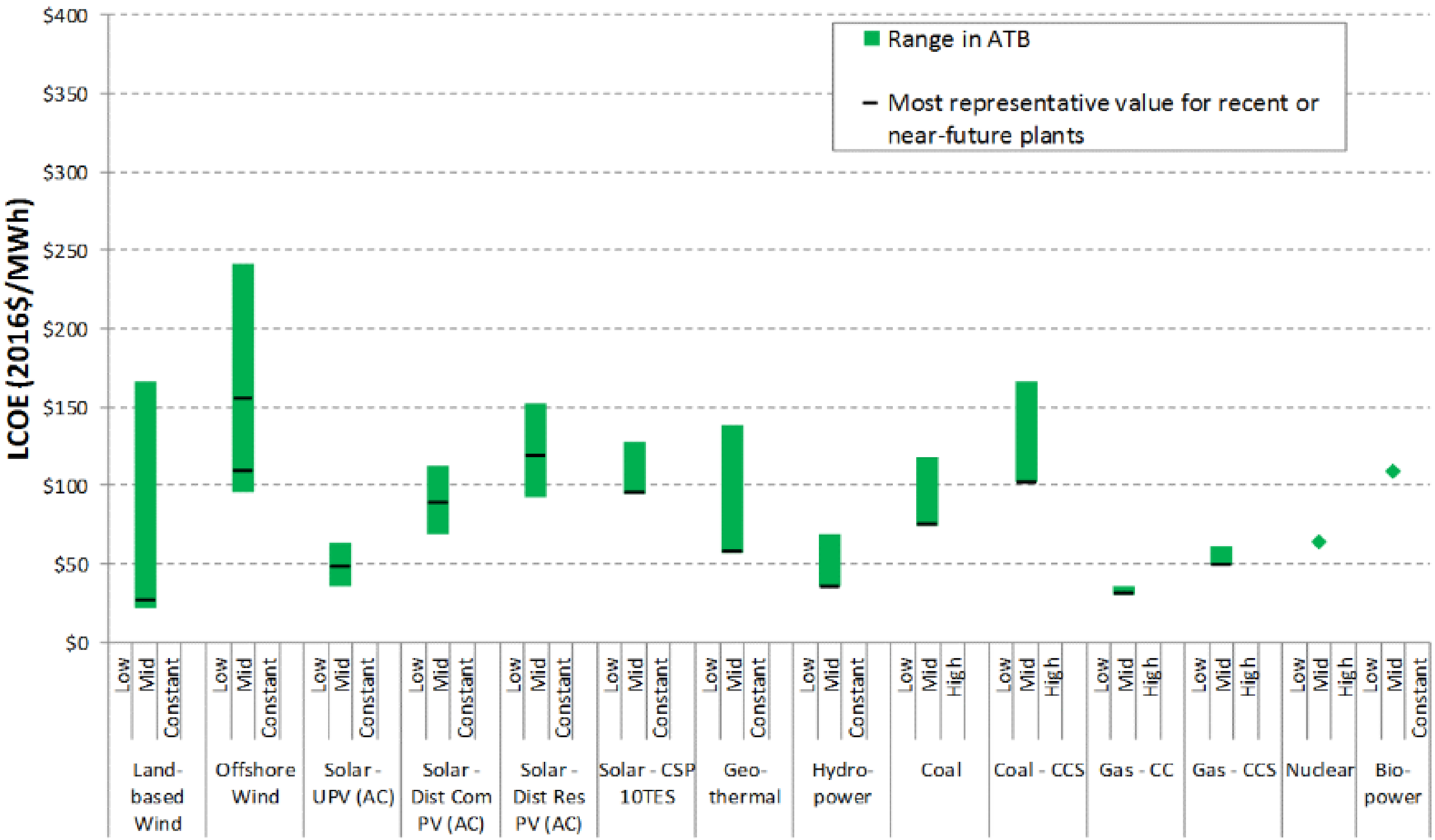
## Property Taxes and Infrastructure Upgrades

- RE development can support the tax base of certain regions.



1.Rynne, S., et al. (2011). Planning for Wind Energy. American Planning Association. Report Number 566. Accessed March 14, 2018. Available at www.planning.org/ research/wind/index.htm

# Current Sources & Costs of Electricity



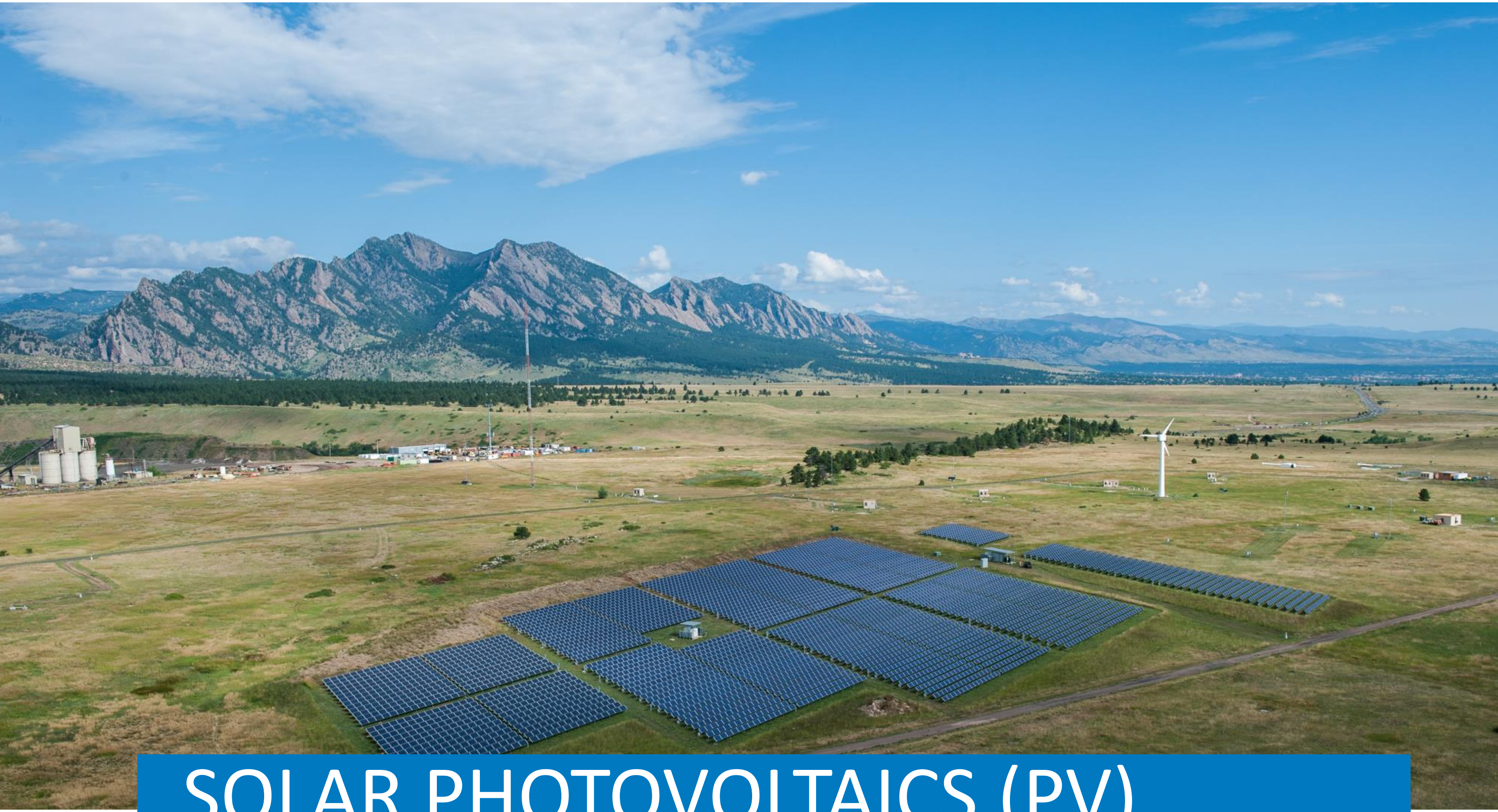

**2018 ATB LCOE range by technology for 2016 based on R&D + Market financial assumptions**

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

Source: NREL Annual Technology Baseline- 2018: https://atb.nrel.gov/electricity/2018/summary.html

# Outline

- Solar
- Wind
- Biomass
- Resources and Tools



# SOLAR PHOTOVOLTAICS (PV)

# Technology Overview

- Direct conversion of sunlight into direct current (DC) electricity
- DC converted to alternating current (AC) by inverter
- Solid-state electronics, no-moving parts
- High reliability, warranties of 20 years or more

- PV modules are wired in series and parallel to meet voltage and current requirements

# Capital & Operating Costs

- The cost of solar has declined precipitously in the past decade, and continues to decrease, albeit at a slower rate.
- Costs below the Annual Technology Baseline estimates have been reported in the marketplace:
  - $1,000/kW installed solar costs and $0.03/kWh PPAs for utility-scale solar projects.

Annual Technology Baseline 2018 PV Cost Estimates

| | Capital Costs | Operating Costs | Levelized Cost of Energy |
|---|---|---|---|
| Utility-Scale | $1,800/kW | $14/kW-year | $0.045/kWh |
| Commercial | $2,600/kW | $18/kW-year | $0.089/kWh |
| Residential | $3,800/kW | $24/kW-year | $0.12/kWh |

# PV Siting Considerations

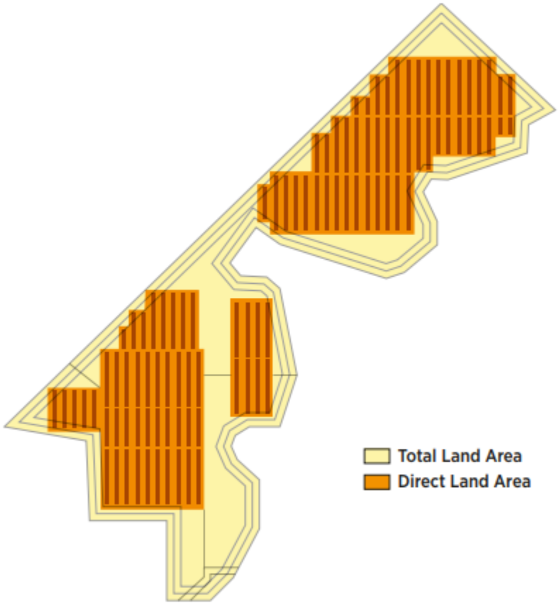
- Rooftop/Canopy:
  - No shading from other buildings, trees, etc.
  - On existing building roofs that have an expected life of at least 15 more years and can accept added load - typically 2-4 pounds (lbs)/$ft^2$
  - Over parking areas, pedestrian paths, etc. – energy generation and sun protection for vehicles in summer
- Ground-mounted solar:
  - Slope <5% likely required for utility-scale; slopes of <3% are preferable.
  - Proximity to existing roads and electrical infrastructure
  - Compromised lands such as landfills and brown fields can be viable

# PV Land Requirements

- Generally, PV requires 5-7 contiguous acres/MW for the entire site footprint, depending on the type of PV system.

**Table ES-1. Summary of Land-Use Requirements for PV and CSP Projects in the United States**

| Technology | Direct Area | | Total Area | |
|---|---|---|---|---|
| | Capacity-weighted average land use (acres/MWac) | Generation-weighted average land use (acres/GWh/yr) | Capacity-weighted average land use (acres/MWac) | Generation-weighted average land use (acres/GWh/yr) |
| **Small PV (>1 MW, <20 MW)** | 5.9 | 3.1 | 8.3 | 4.1 |
| Fixed | 5.5 | 3.2 | 7.6 | 4.4 |
| 1-axis | 6.3 | 2.9 | 8.7 | 3.8 |
| 2-axis flat panel | 9.4 | 4.1 | 13 | 5.5 |
| 2-axis CPV | 6.9 | 2.3 | 9.1 | 3.1 |
| **Large PV (>20 MW)** | 7.2 | 3.1 | 7.9 | 3.4 |
| Fixed | 5.8 | 2.8 | 7.5 | 3.7 |
| 1-axis | 9.0 | 3.5 | 8.3 | 3.3 |
| 2-axis CPV | 6.1 | 2.0 | 8.1 | 2.8 |



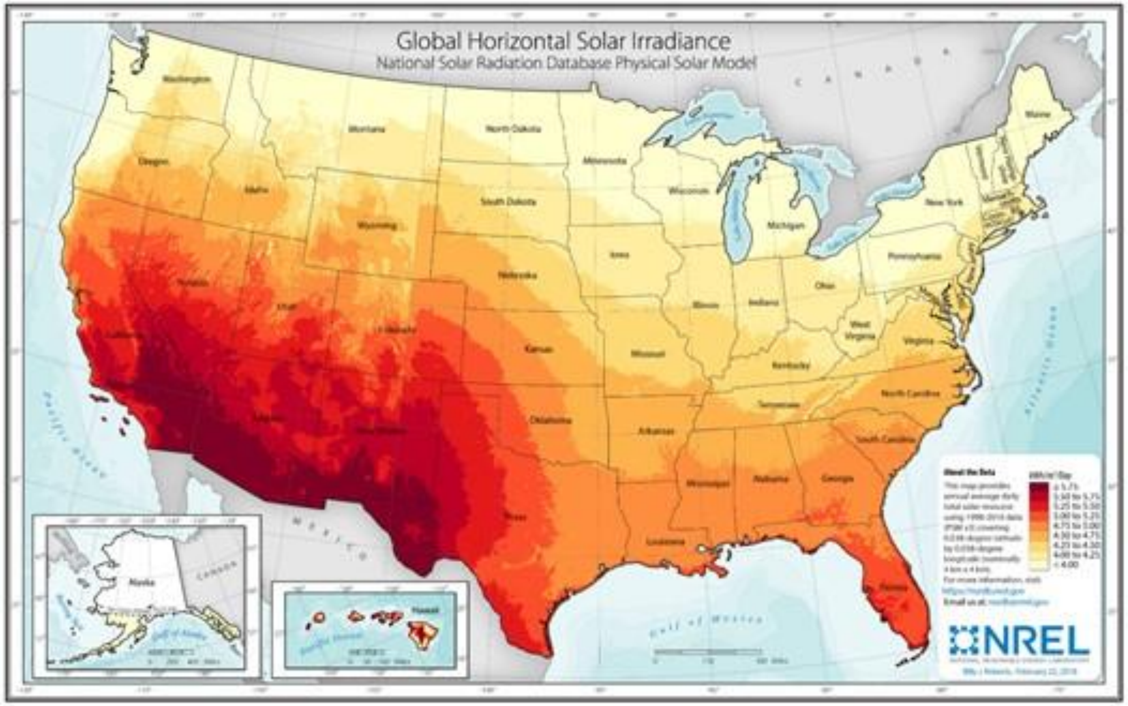

In addition to the area covered by the PV array, additional land area is required for setbacks, access roads, fencing, and a possible substation.

*Example of total vs. direct land use in a ground-mount PV system*[6]

Ong et al. 2013

# Estimating Production

- Varies from 3–6 $kWh/m^2/day$ in most of U.S
- Net Capacity Factor depends on axis and tilt:
  - Fixed:
    15% to 20%
  - Single Axis:
    20% to 27%




Use PV Watts to estimate production

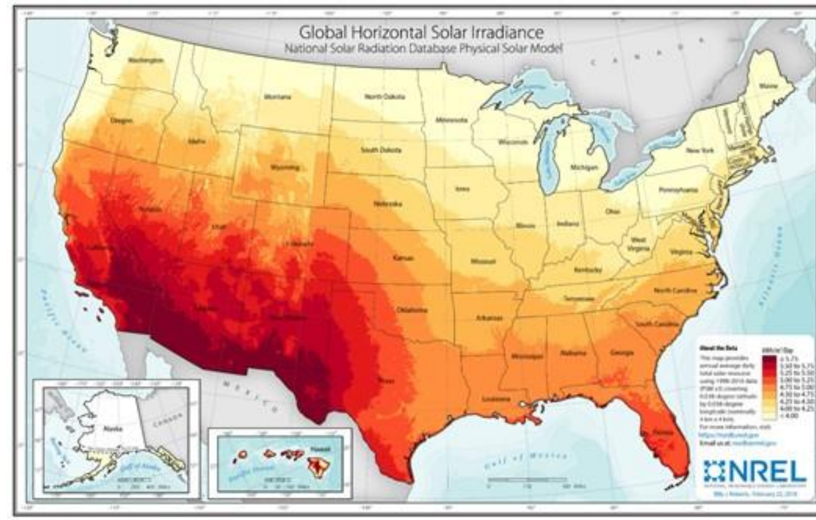
- [https://pvwatts.nrel.gov/](https://pvwatts.nrel.gov/)

Estimates per NREL ATB 2018

# Calculating Solar Production

<u>Detailed:</u>

- System size ($kW_{DC}$)*Capacity Factor (%) * 8,760 (hours)
  - Consult RE Atlas for production estimates




<u>“Rule of Thumb” for fixed tilt PV:</u>

- System size ($kW_{DC}$)* Annual Energy production (kWh/kW)
  - Use reference areas in the map and table to the right

| Location | Annual Energy Production (kWh/kW) |
|---|---|
| **Utility PV - Seattle** | 1,102 |
| **Utility PV - Chicago** | 1,295 |
| **Utility PV - Kansas City** | 1,420 |
| **Utility PV - Los Angeles** | 1,595 |
| **Utility PV - Daggett, CA** | 1,823 |

Estimates per NREL ATB 2018

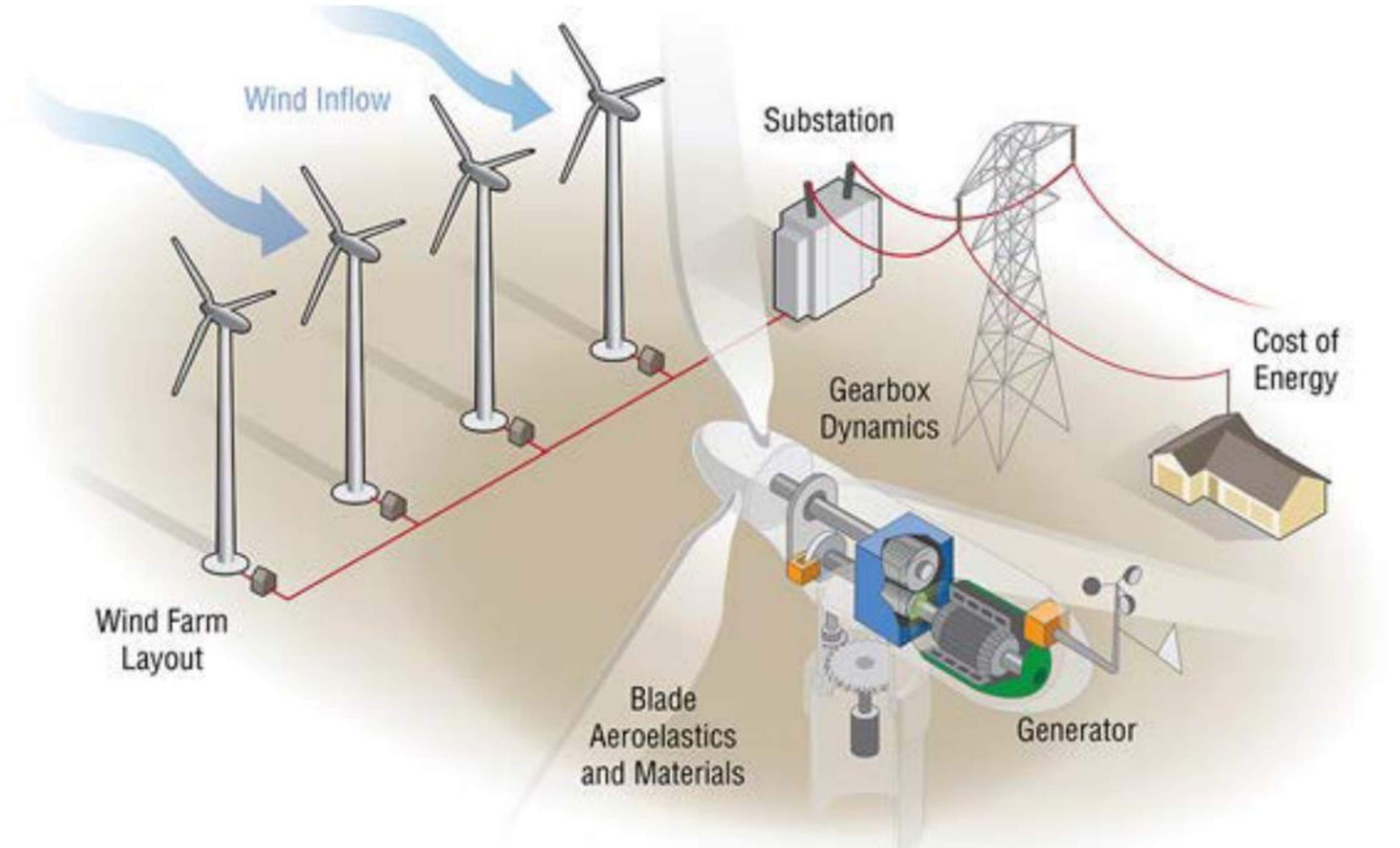
# Job Requirements

- Primarily construction-oriented, limited full-time operating staff required
- Construction (1-2 years): ~11 job-years /MW DC (1,100 jobs for a 100 MW solar farm)
- Operations (20-30 years): ~0.1 job-years/MW DC (10 jobs for a 100 MW solar farm)

Based on NREL utility project data

# ONSHORE WIND

# Technology Overview




*Simplified schematic of a Wind Turbine Generator. Illustration by Alfred Hicks, NREL*

# Technology Overview

Photo from Bergey Windpower Co. Inc., NREL 02102

## Small (≤100 kW)

Homes

Farms

Remote applications (e.g., water pumping, telecom sites, ice making)

Photo from Tjaden Farms, NREL 13764

## Mid-scale (100 kW – 1,000 kW)

Village power

Hybrid systems

Distributed power

## Large, land-based (1 MW – 3 MW)

Utility-scale wind farms

Large distributed power

Photo from HC Sorensen, NREL 17855

## Large, offshore (3 MW – 7 MW)

Utility-scale wind farms, shallow coastal waters

# Capital & Operating Costs

- Capital Costs
  - Utility-Scale: $1,500-$1,700/kW
- Operating Costs
  - ~$50/kW-year
- Levelized Cost of Energy:
  - $0.037/kWh to $0.169/kWh
  - Very resource-dependent

# Siting and Land Requirements

- Land requirements for wind are unique, because they require very large tracts of land for turbine spacing, but only disturb a small portion of the land.
    - Permanent land requirement: ~1 acre/MW
    - Temporary land requirement: ~2 acres/MW
    - Total land requirement: 25- 124 acres/MW

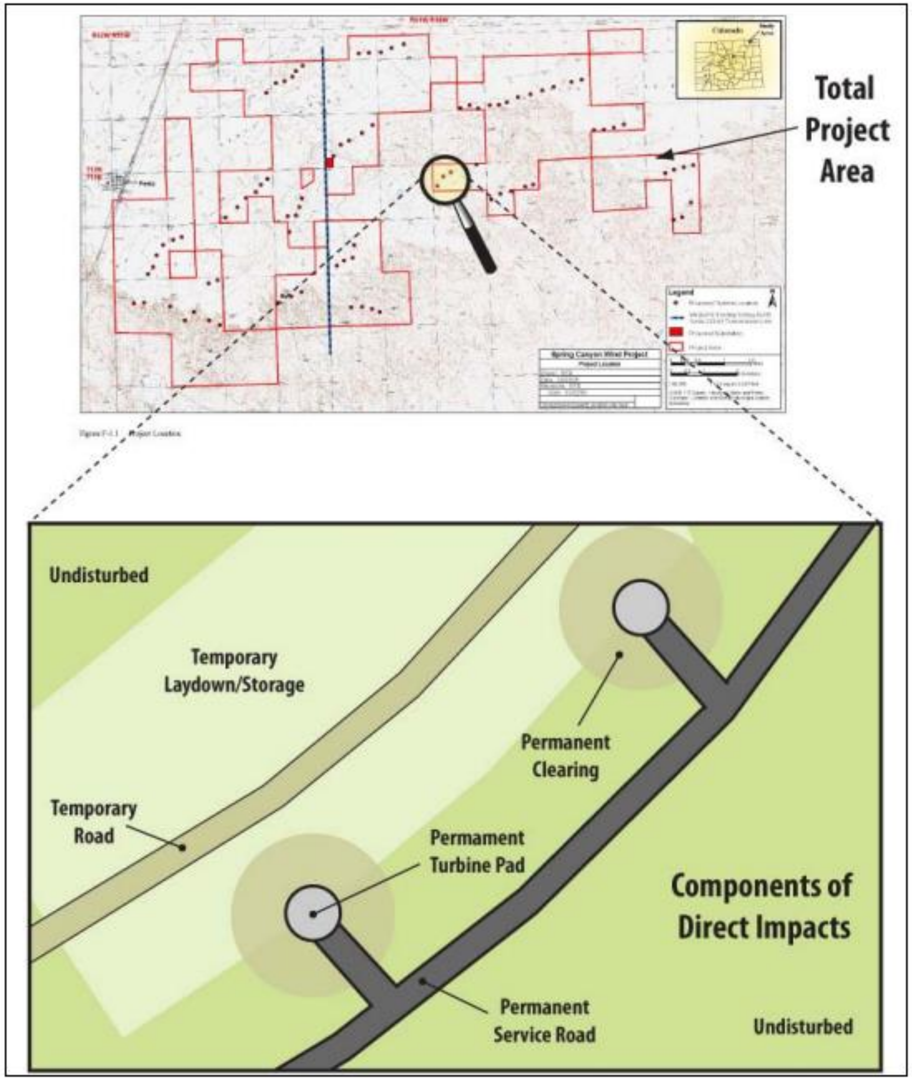



Figure 1. Illustration of the two types of wind plant land use: total area and direct impact area (including permanent and temporary)[1]

Citation: Denholm et al. 2009

# Siting and Land Requirements

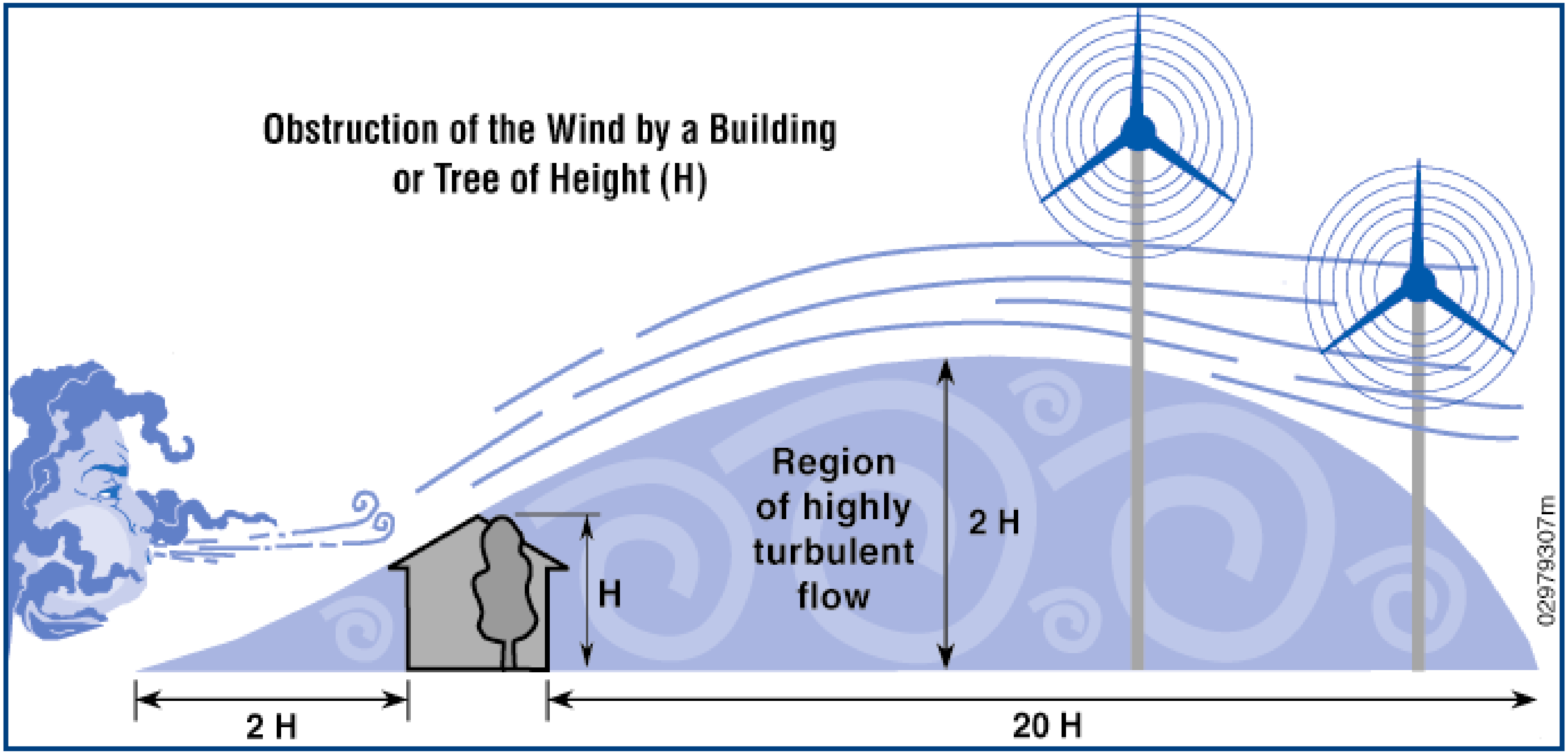
- Siting is very resource dependent, and developers will typically install 3-10 meteorological towers for 1-4 years to measure the wind resource before investing.

- Presence of avian migration pathways, proximity to population centers, and presence of NEPA criteria are major siting concerns.

- Setbacks are county-dependent: Turbines will need to be at least 1.1 x structure height away from roads, property lines, and electric lines. They will also need to be at a distance of at least 5x the rotor diameter from other turbines.

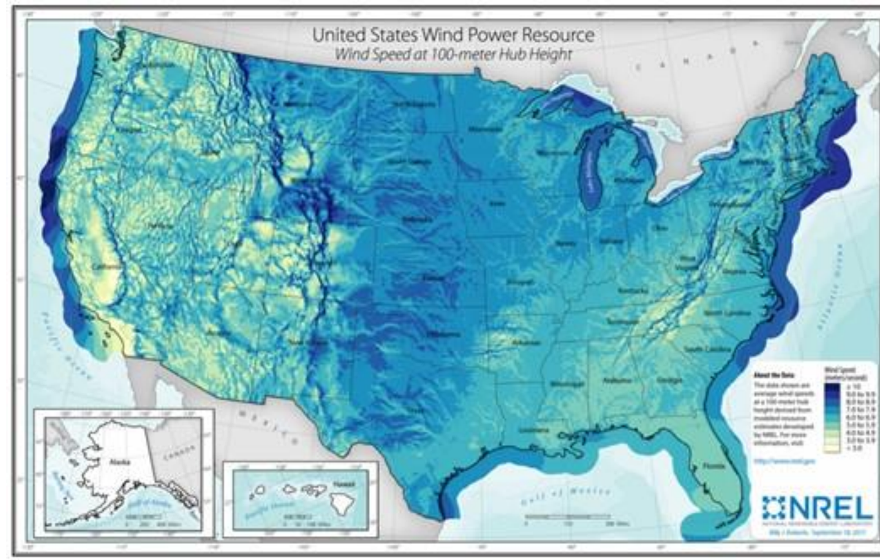
Citation: Denholm et al. 2009

# Turbulence and Micrositing



# Estimating Production

- Production varies considerably geographically (average wind speeds of 4m/s to 9 m/s)
  - This results in a range in capacity factors of 11% to 48%




- Use the wind prospector tool to estimate production:
  - [https://maps.nrel.gov/wind-prospector/](https://maps.nrel.gov/wind-prospector/)

| Wind Speed Range (m/s) | Weighted Average Wind Speed (m/s) | Weighted Average Net CF (%) |
|---|---|---|
| 8.2 - 13.5 | 8.7 | 47.4% |
| 8.0 - 10.9 | 8.4 | 46.2% |
| 7.7 - 11.1 | 8.2 | 45.0% |
| 7.5 - 13.1 | 7.9 | 43.5% |
| 6.9 - 11.1 | 7.5 | 40.7% |
| 6.1 - 9.4 | 6.9 | 36.4% |
| 5.4 - 8.3 | 6.2 | 30.8% |
| 4.7 - 6.9 | 5.5 | 24.6% |
| 4.0 - 6.0 | 4.8 | 18.3% |
| 1.0 - 5.3 | 4.0 | 11.1% |

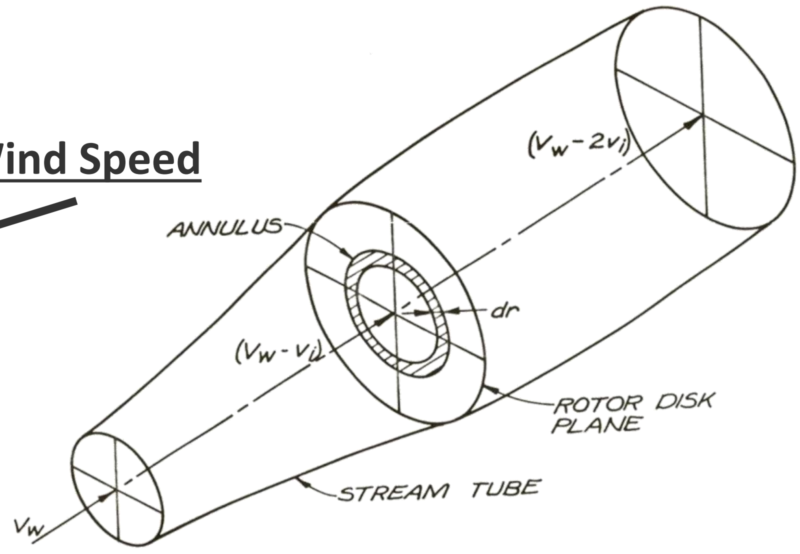
Estimates per NREL ATB 2018

# Resource: Power in the Wind

Efficiency · Air Density · Rotor Area · Wind Speed

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

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




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

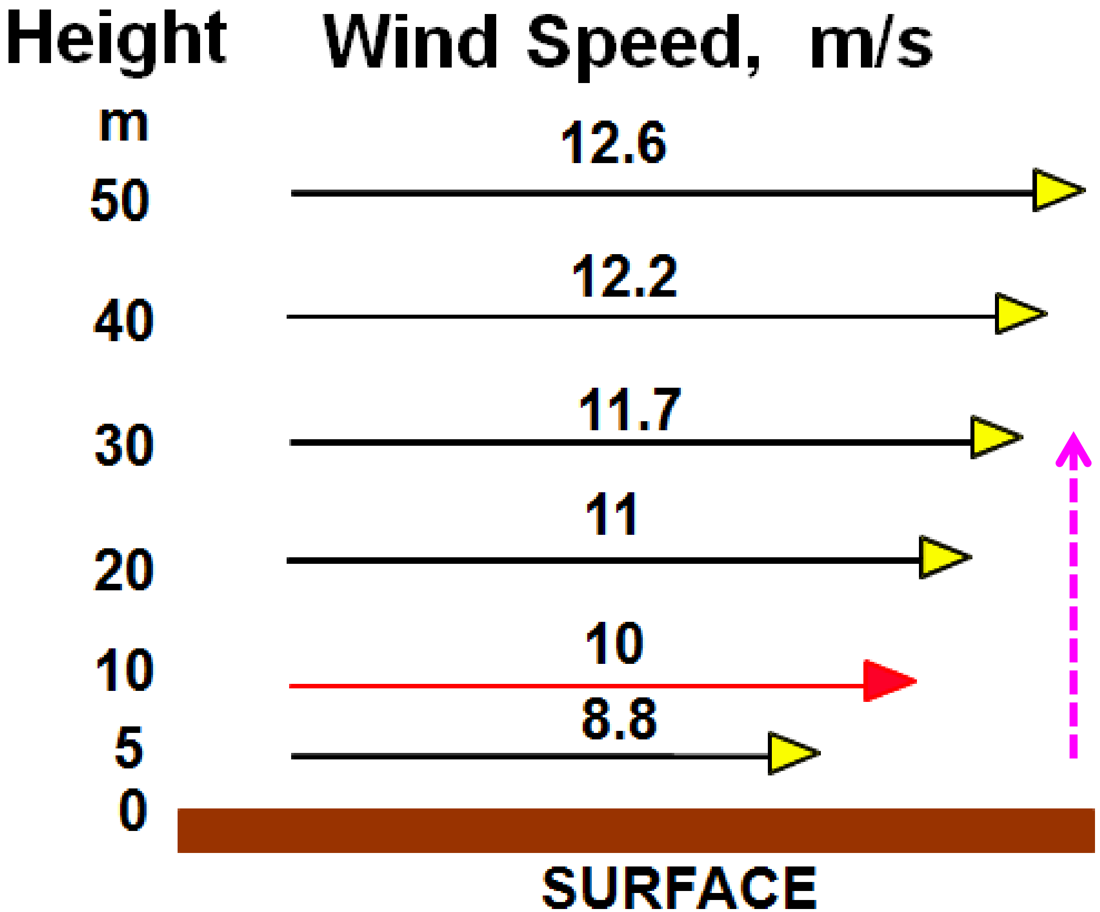
– 25% higher wind speed ≈ **2 times the power** available

– 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: Wind Shear




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

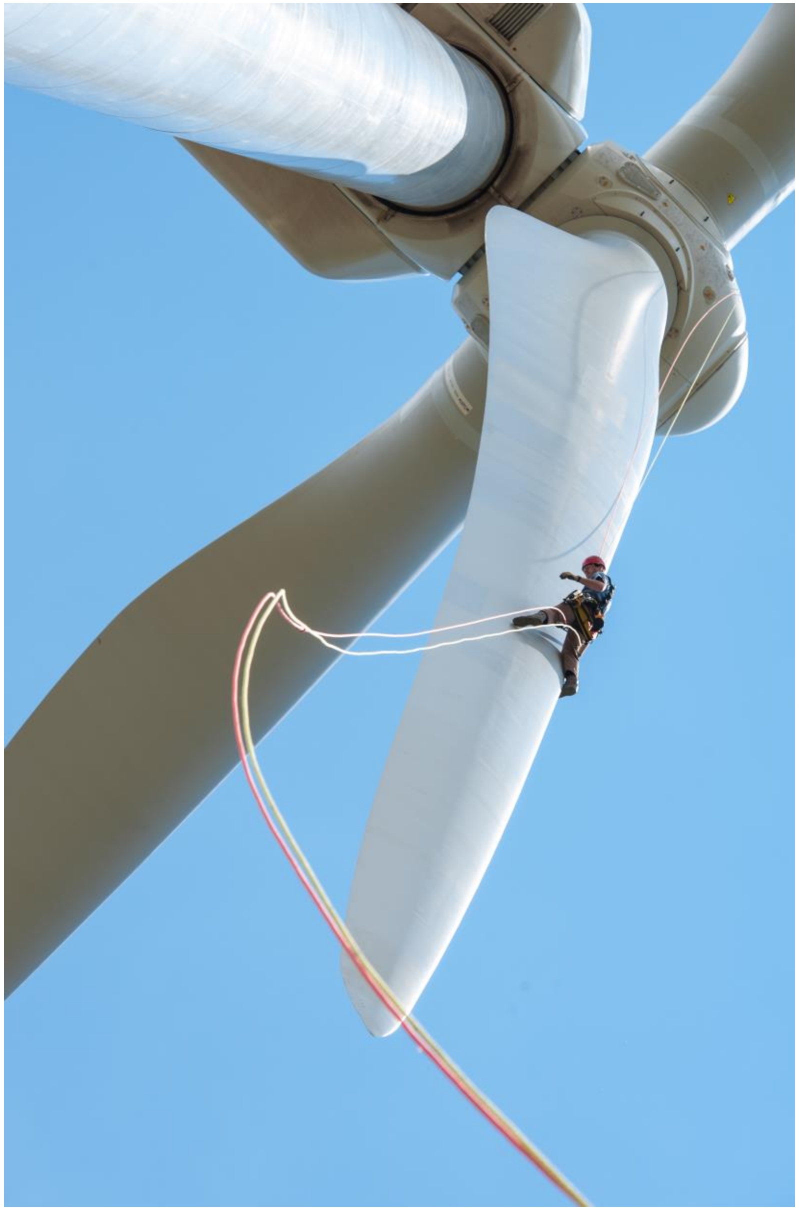
That is why “taller towers” is often the first answer to “how can the wind turbine energy production be increased at this location?”

Courtesy of Alternative Energy Institute

# Job Requirements

- ~4 job-years/MW during construction (400 full time jobs for a 100MW wind farm)

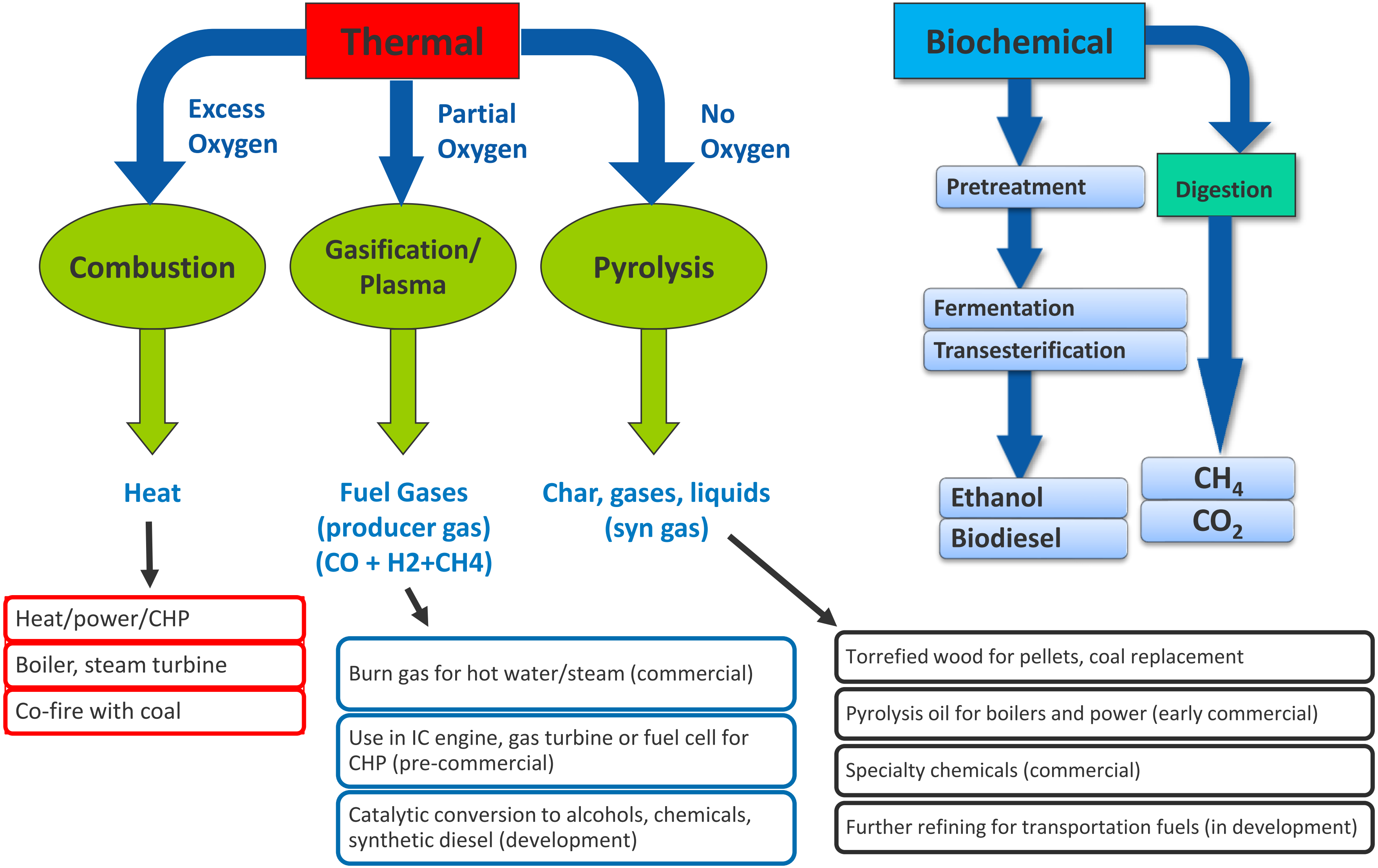
- This falls to 0.16 job-years/MW during operations (or 16 jobs for the 100 MW wind farm discussed above)



(JEDI model 2018 default inputs)

# BIOMASS

# Biomass Technology Overview



# Technology Overview: Resources

## Biomass Feedstock

- Trees
- Grasses
- Agricultural Crops
- Residues
- Animal Wastes
- Municipal Solid Waste
- Algae
- Food Oils, Waste Oils

## Conversion Process

- Combustion
- Gasification
- Pyrolysis
- Co-firing
- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation
- Trans-esterification

## Products

**Fuels**
- Ethanol
- Biodiesel
- "Green" Gasoline & Diesel

**Power**
- Electricity
- Heat

**Chemicals**
- Plastics
- Solvents
- Chemical Intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty Acids
- Acetic Acid
- Carbon Black
- Paints
- Dyes, Pigments, and Ink
- Detergents
- Etc.

**Food and Feed**

Photos left to right: NREL/PIX 05086, 12481

# Capital & Operating Costs

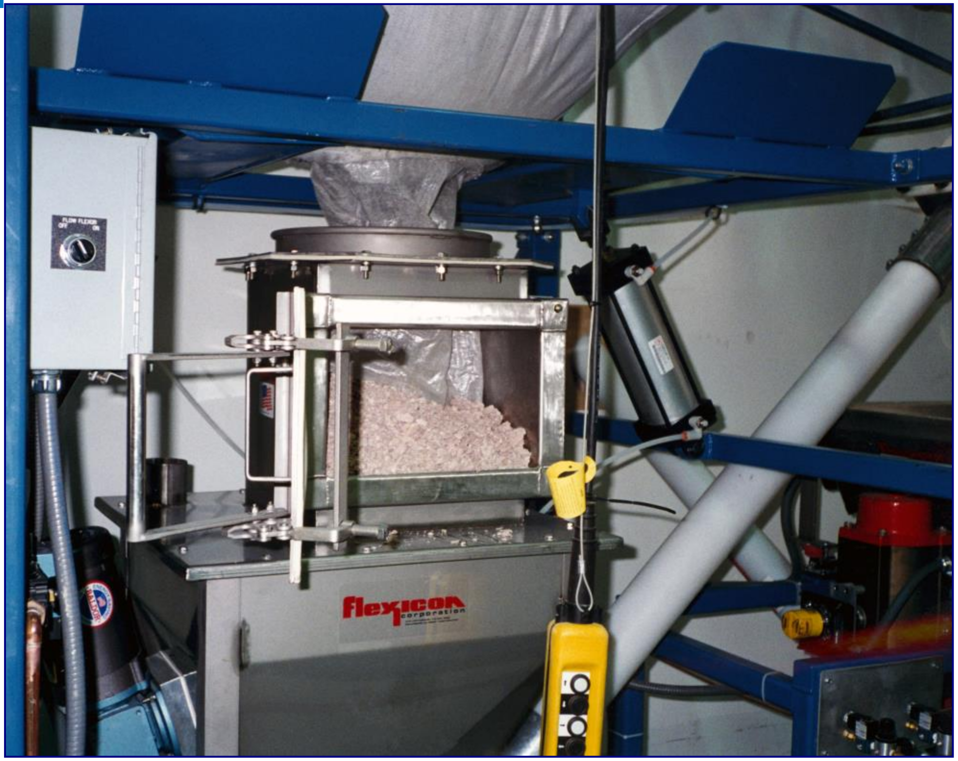
- Capital Costs
  - ~$4,000/kW
- Operating Costs
  - $110/kW-year
  - $0.005/kWh
- Levelized Cost of Energy
  - $0.109/kWh
- Economies of scale are typically required for plants to be cost-effective (at least 10 MW)

Biomass Heat Exchanger

# Siting and Land Requirements

Project feasibility depends on:

- Availability and cost of each type of biomass (chips, pellets, or logs)
  - Feedstock should be less than 50 miles away
- Competing fuel cost (e.g., fuel oil, natural gas, etc.)
- Peak and annual thermal load
- Building size and type
- Space availability
- Operation and maintenance staff availability and experience
- Local emissions regulations




Dried paper mill sludge is fed into the hopper at a biorefinery plant.

NREL Photo #07713

# Estimating Production

- Dependent on feedstock availability, estimated at 56% capacity factor by ATB 2018.
- Use the Tribal Energy Atlas to estimate resource potential
- https://maps.nrel.gov/tribal-energy-atlas/
- **Verify resource through discussions with local feedstock providers (dairy operations, paper mills, etc.)**

# Job Requirements

- Per NREL expert estimates, a 50 MW plant would typically require 15 to 40 full-time employees for electrical and mechanical supervision, feedstock processing, plant operations and maintenance, etc.
- Biomass plants generally require 15-40 job-years regardless of their size, meaning that larger plants are required to achieve sufficient economies of scale.

# Tools and Resources:

- Maps of Resources/ Resource Estimates:
  - Tribal Energy Atlas
  - Renewable Energy Atlas: https://maps.nrel.gov/re-atlas/
- NREL Annual Technology Baseline
  - https://atb.nrel.gov/
- PVWatts: http://www.nrel.gov/rredc/pvwatts/
- WindExchange: https://windexchange.energy.gov/
- Solar Decision Tree (EPA) https://www.epa.gov/sites/production/files/2015-10/documents/repower_technologies_decision_tree.pdf

# Thank You

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