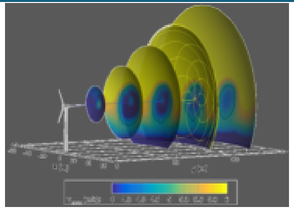
SAND2021-13767PE

Sandia National Laboratories

An Overview of Wind Energy Systems and Future Research Opportunities



PRESENTED BY

Josh Paquette

U.S. DEPARTMENT OF ENERGY NNSA

History of Wind Energy
pre - 1970

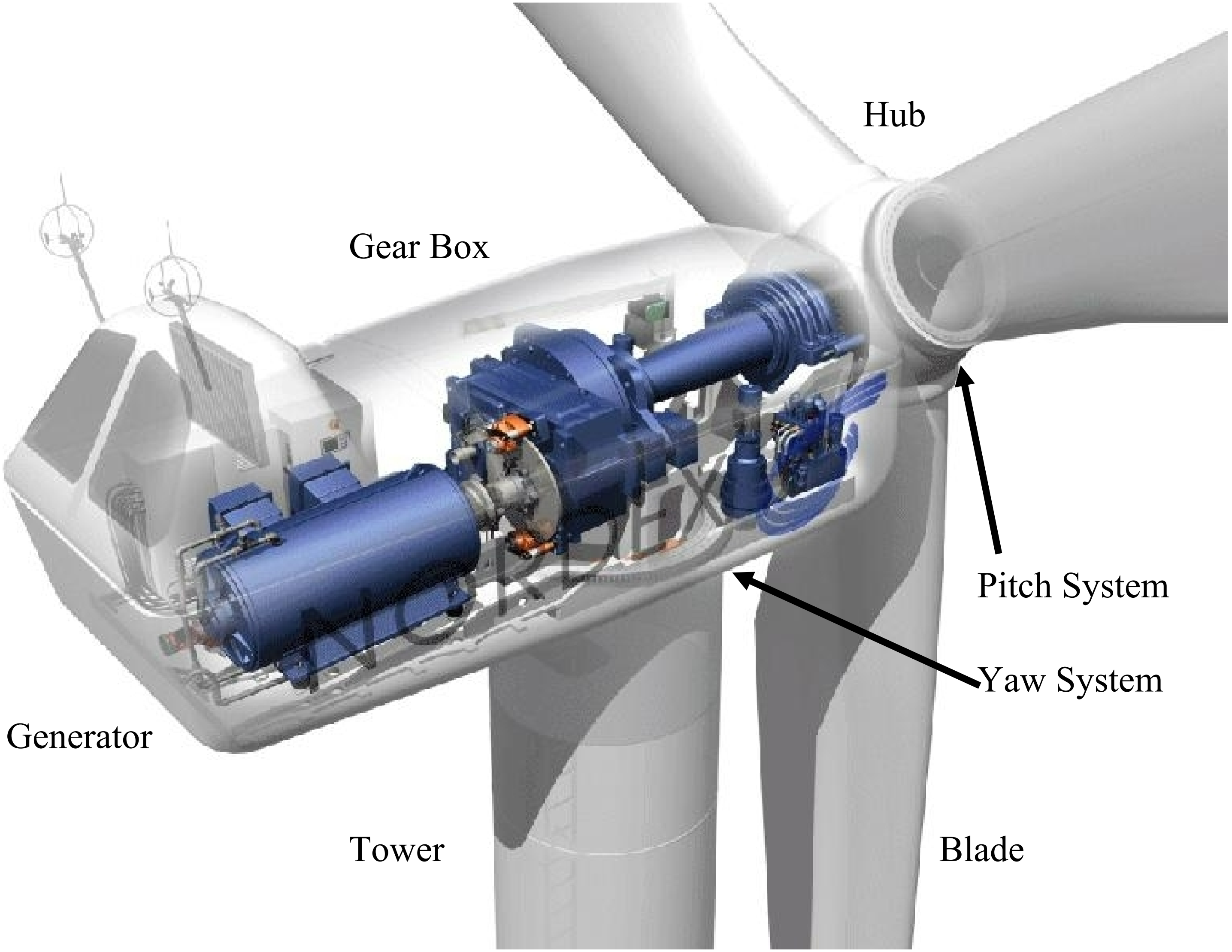
Prehistoric – Maritime (Greek, Viking)

Medieval – Persian, Greek, England

20th Century – Great Plains

First Energy Shortage -- 1974

Wind Power Basics
Modern Turbine Design



Wind Power Basics

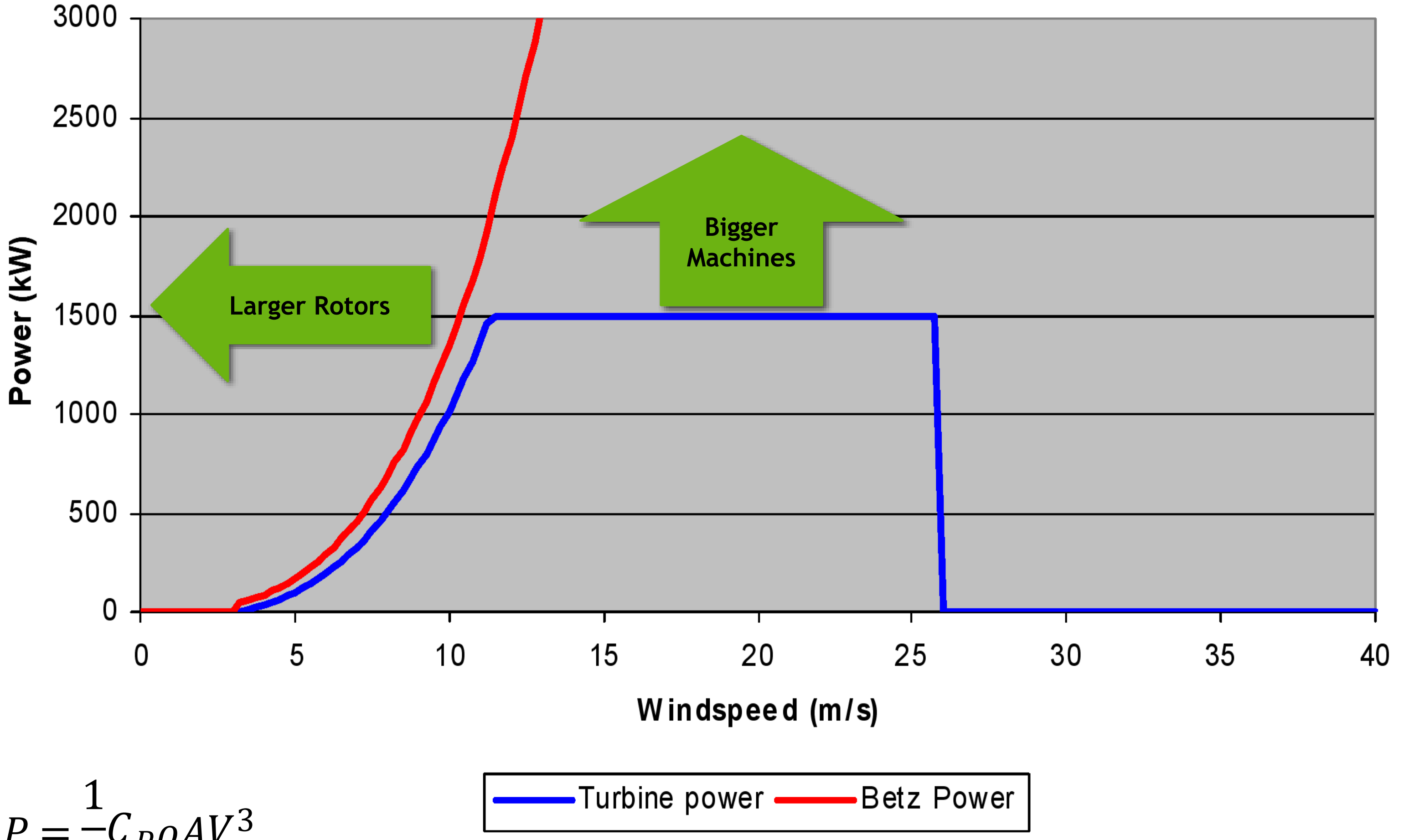
Wind Power output is proportional to the area swept by the blades ($A = \pi r^2$)

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

Wind Power output is proportional to wind speed cubed.

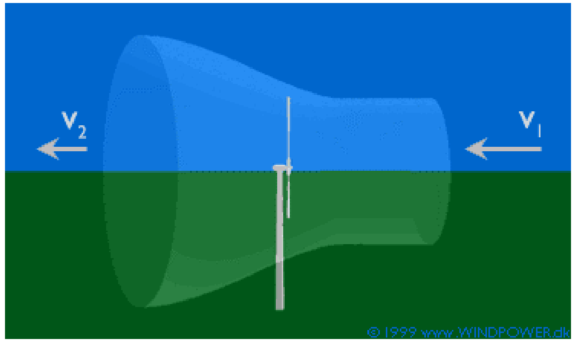
ρ = Air Density
A = Area swept by blades
V = Wind speed

Wind Power Basics
Power vs. Wind Speed



$$P = \frac{1}{2} C_P \rho A V^3$$

Conversion Coefficient



$$m = \rho A \left(\frac{V_1 + V_2}{2} \right)$$

$$P = \frac{1}{2} m (V_1^2 - V_2^2)$$

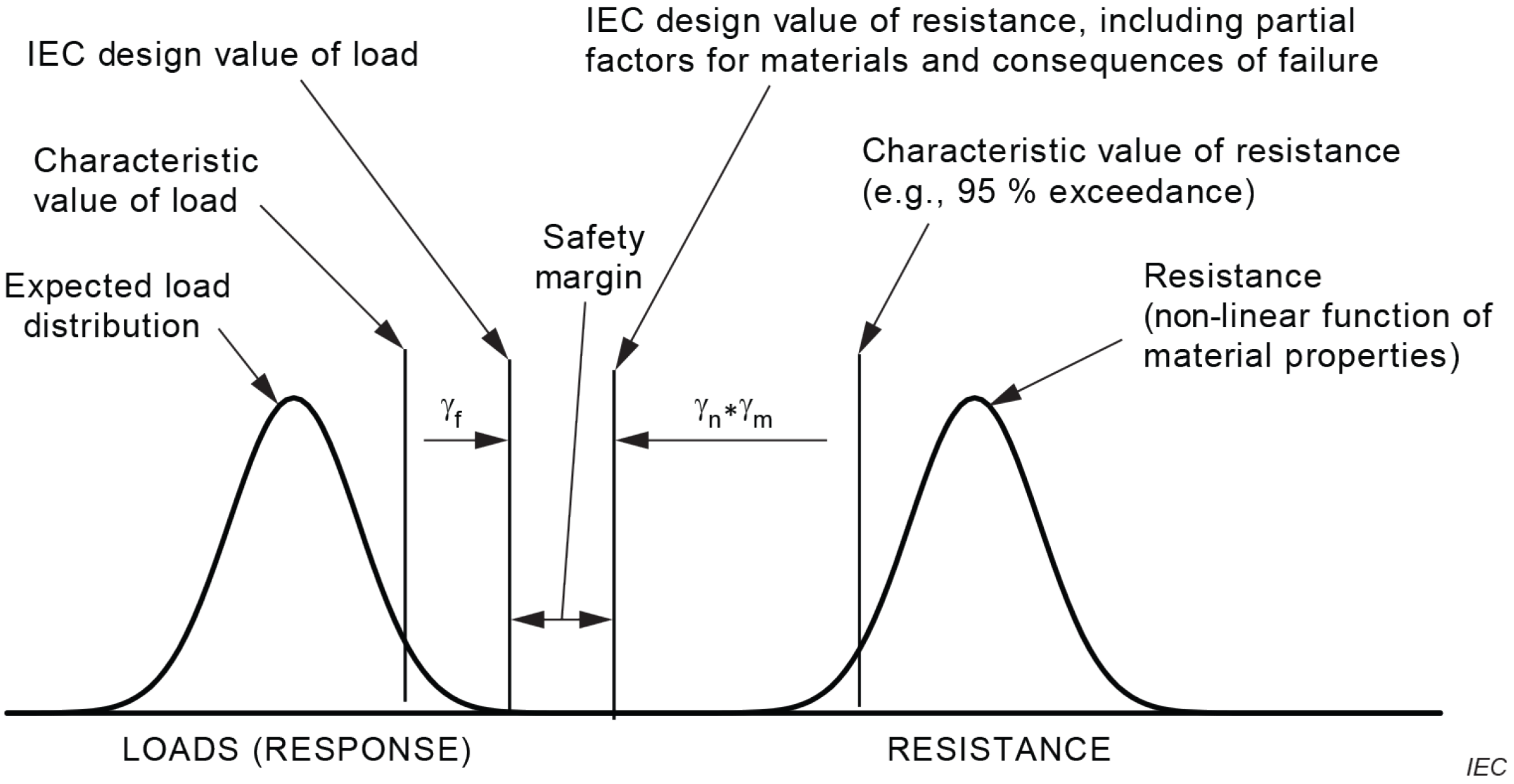
$$P_0 = \frac{1}{2} \rho A V_1^3$$

$$\frac{P}{P_0} = \frac{1}{2} \left(1 - \left(\frac{V_2}{V_1} \right)^2 \right) \left(1 + \frac{V_2}{V_1} \right)$$

$$\max \left(\frac{P}{P_0} \right) = \frac{16}{27} = 0.593$$

Source:
windpower.org

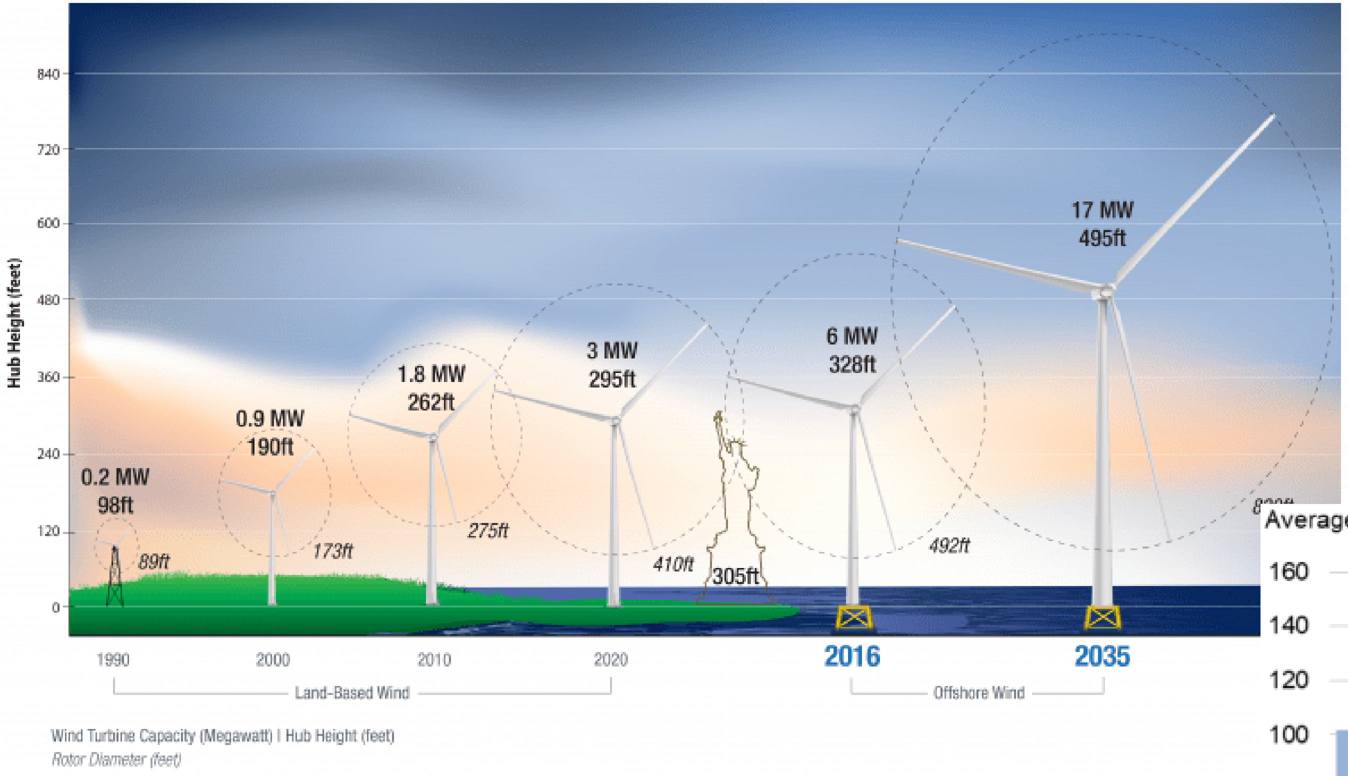
Wind Power Basics
Component Design

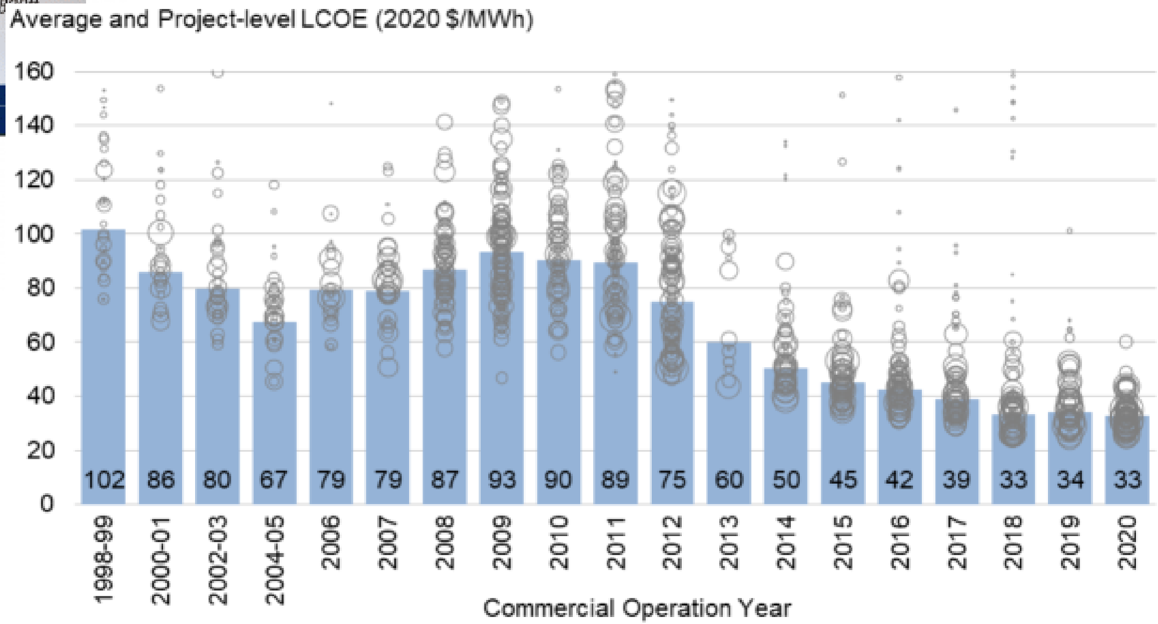


Source: IEC 61400-5

Wind Power Trends

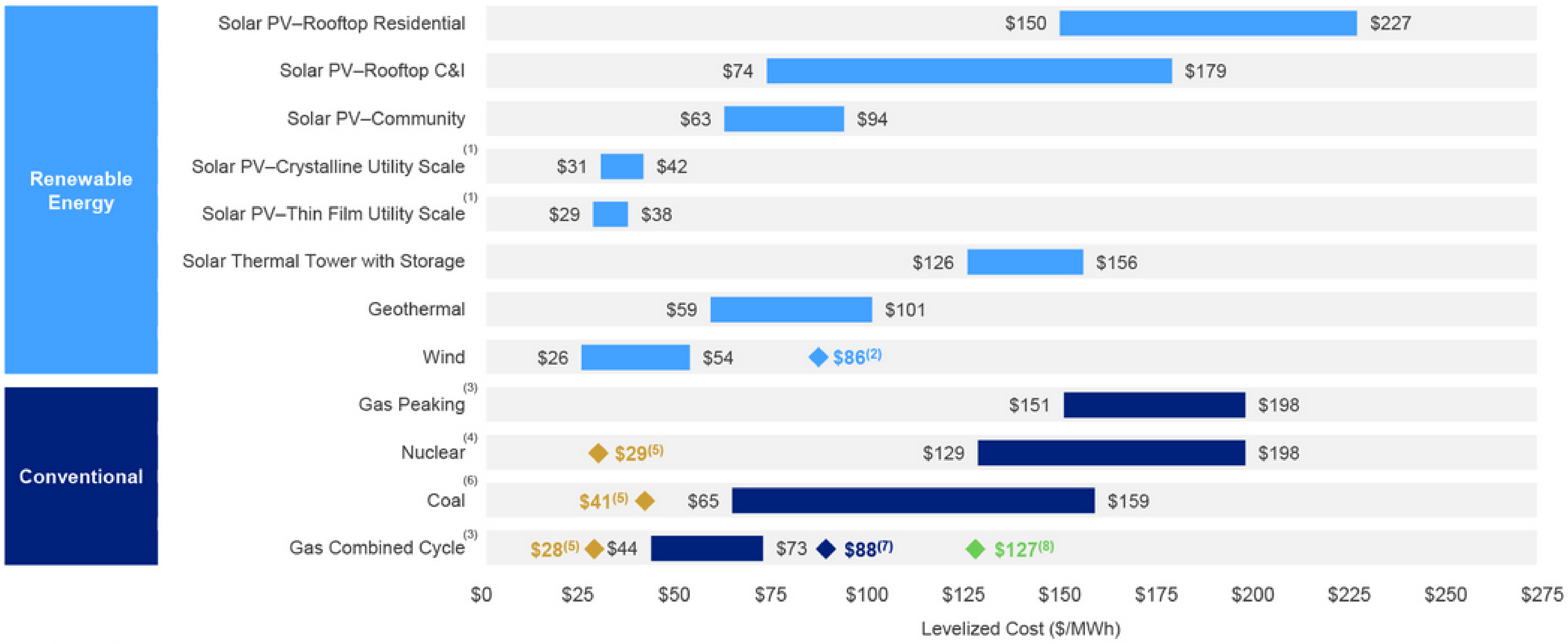
Larger Turbines *Have Led* to Cheaper Energy





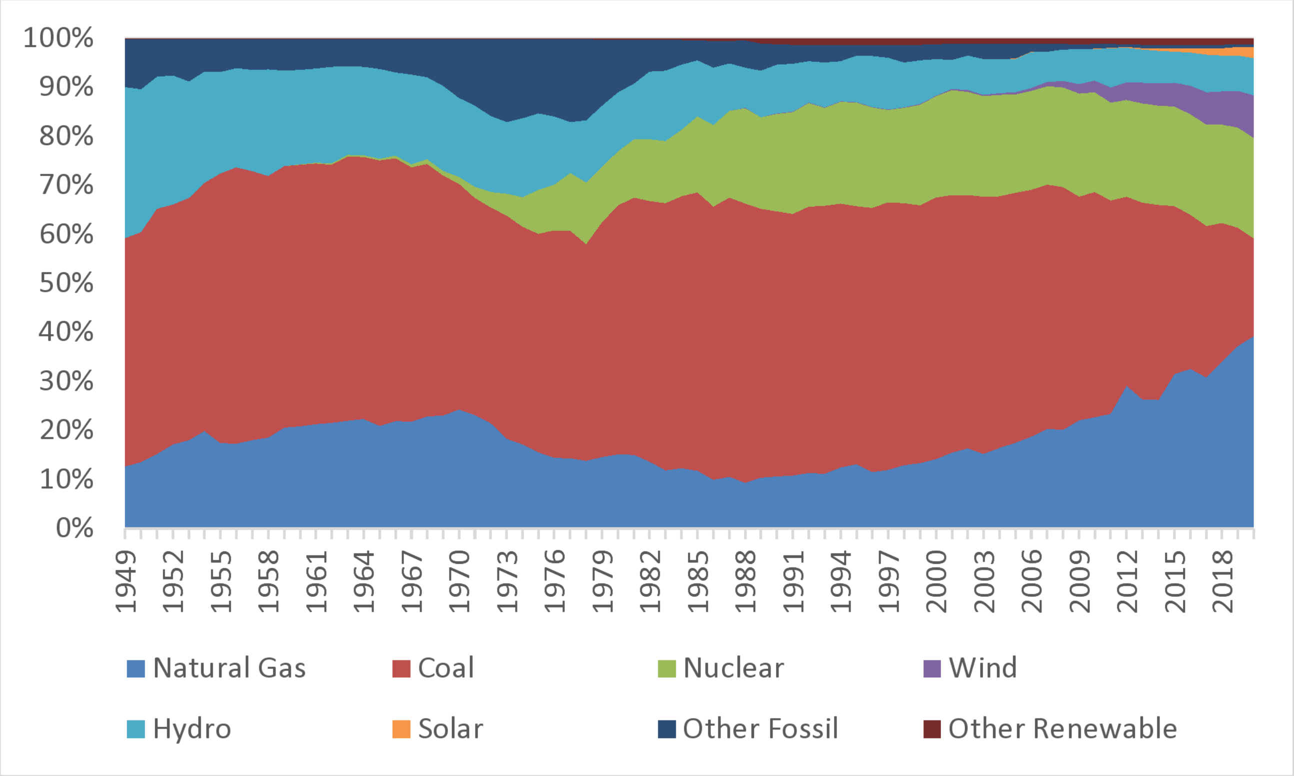
Source: DOE/LBNL 2021

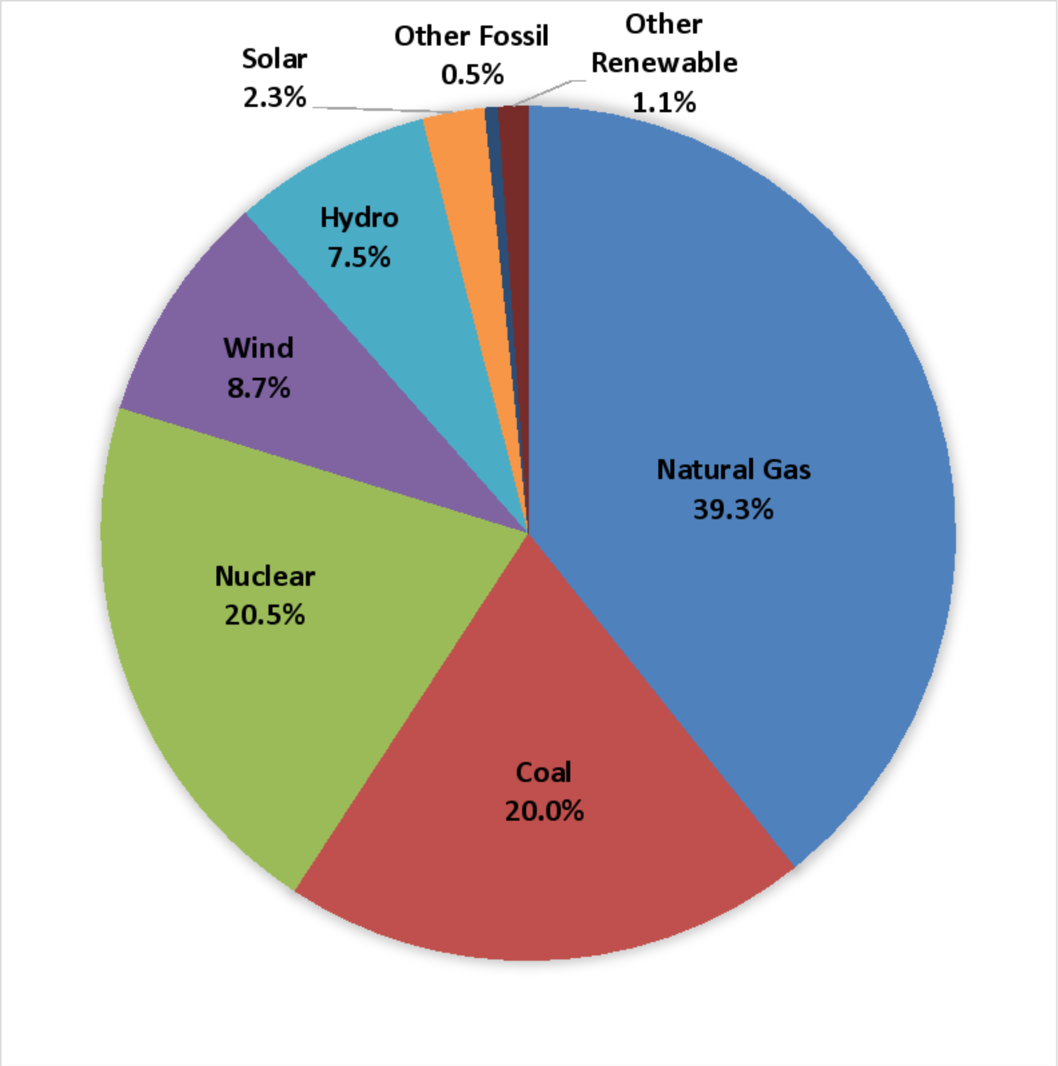
Wind Power Trends
Cost of Energy Comparison



Source: Lazard, 2020

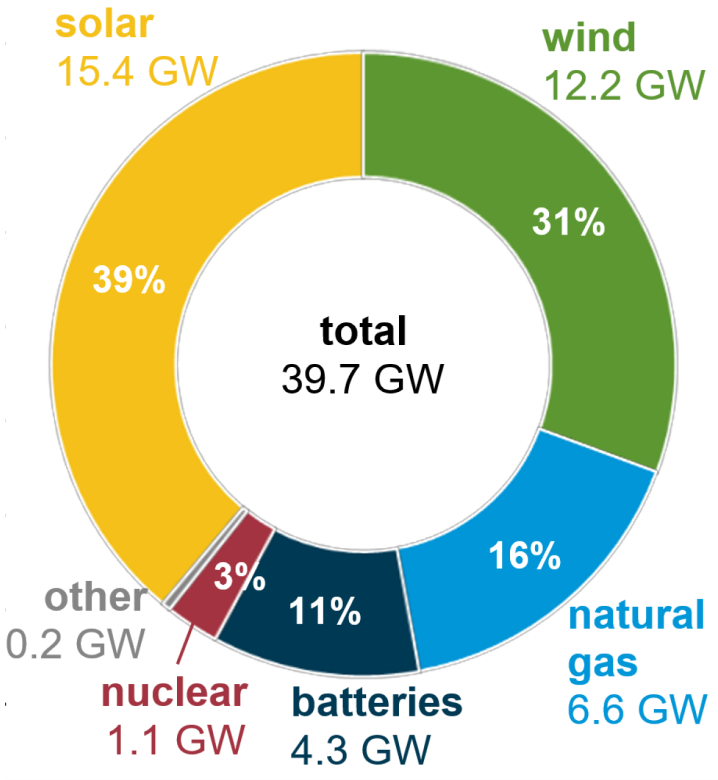
Wind Power Trends
Energy Mix

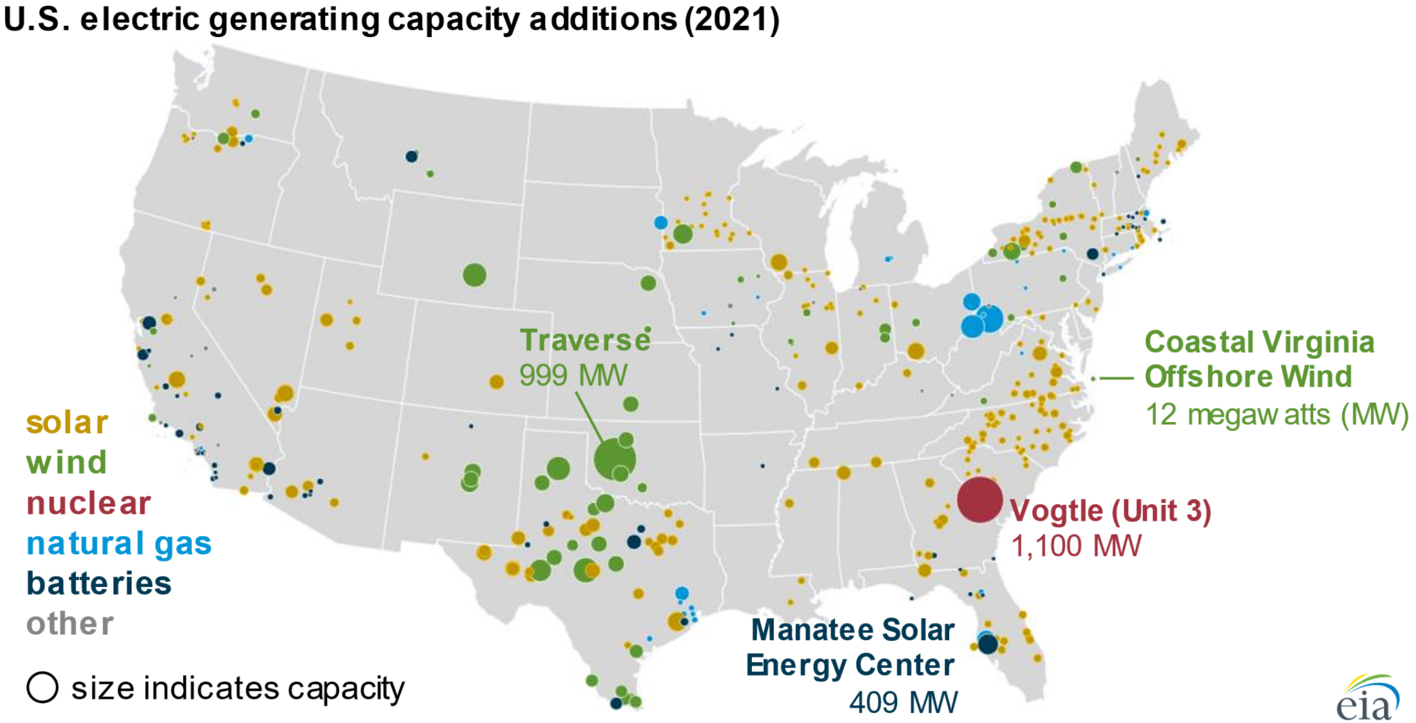




Source: DOE-EIA

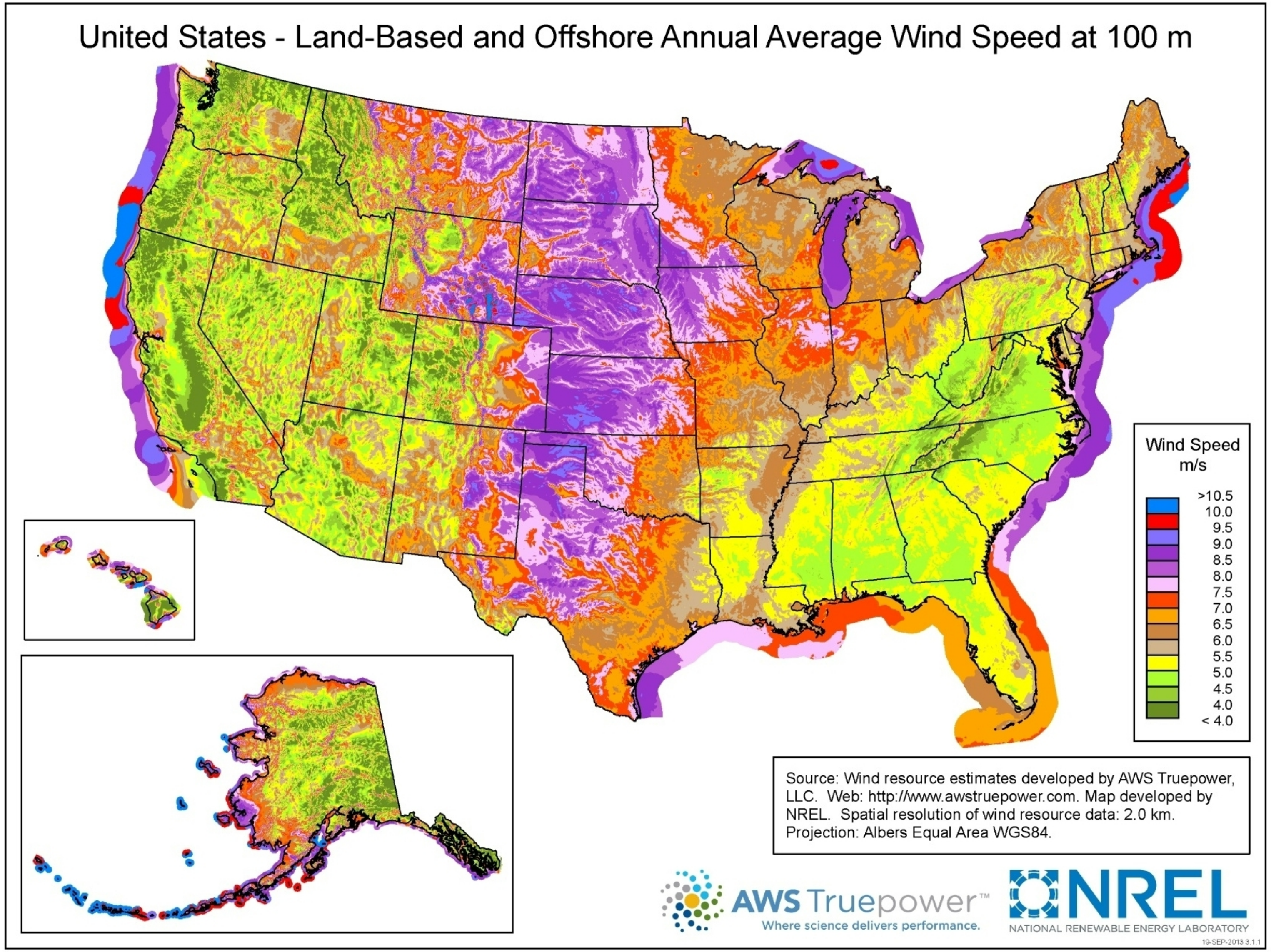
Wind Power Trends
Deployment



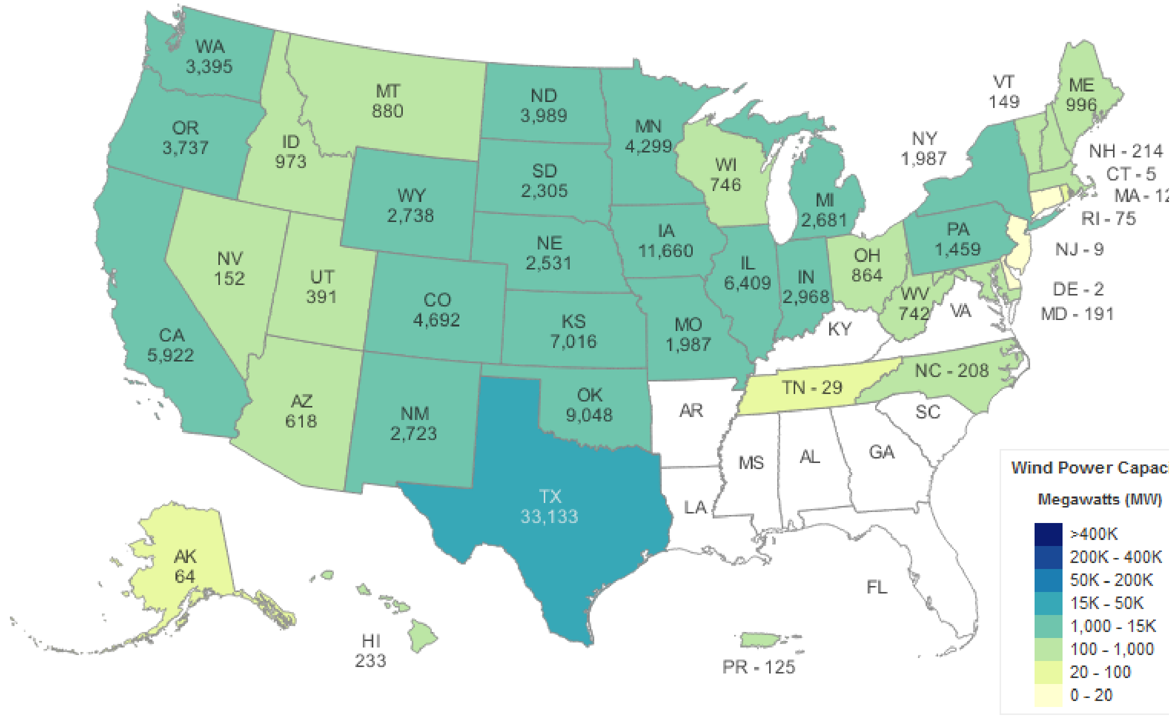


Source: DOE-EIA

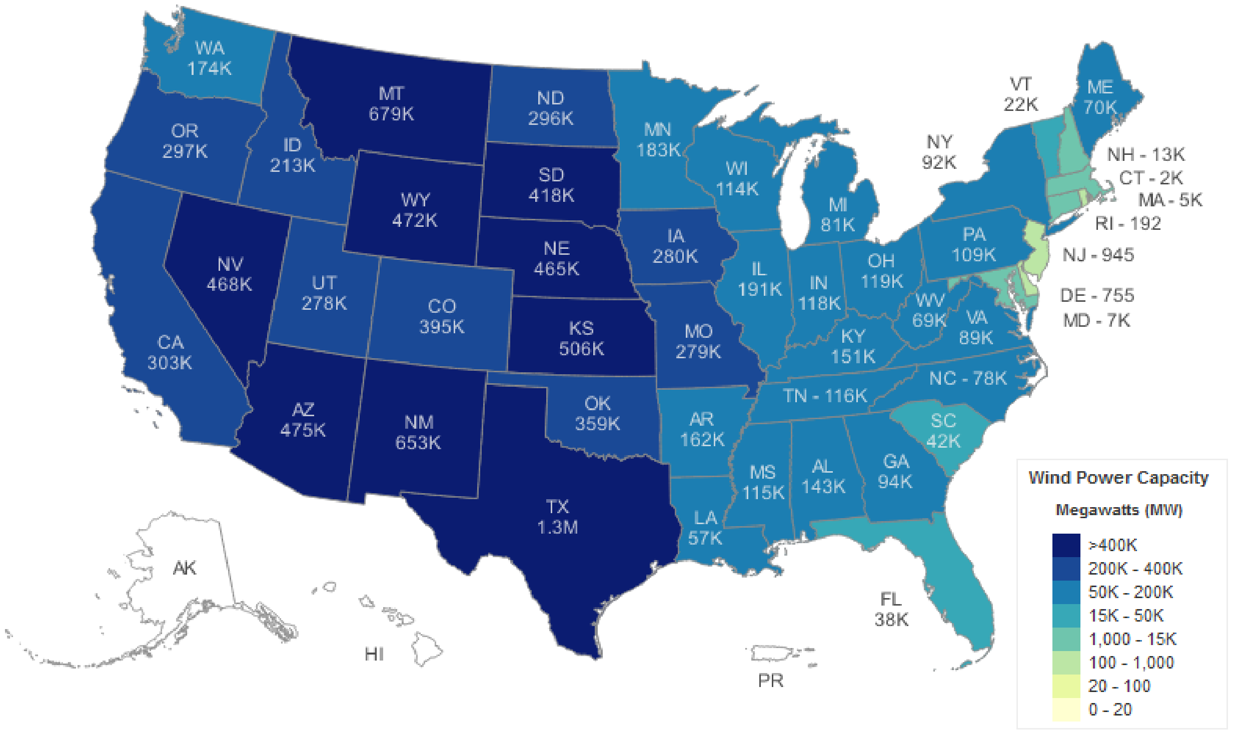
U.S. Wind Resource



Wind Power Generation



Total Installed Wind Capacity: 122,465 MW

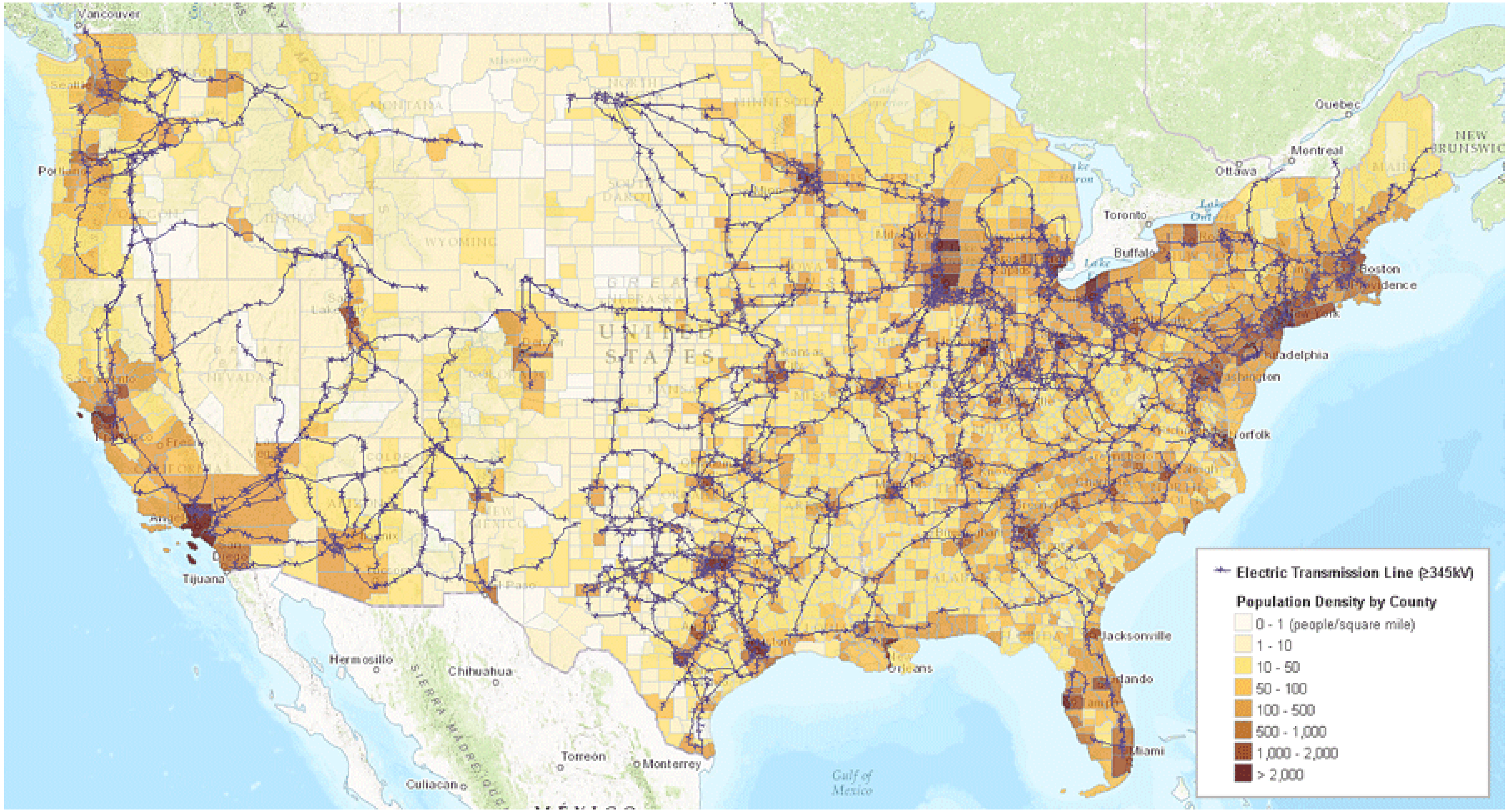


Total Potential Wind Capacity: 10,640,080 MW

~39M Homes

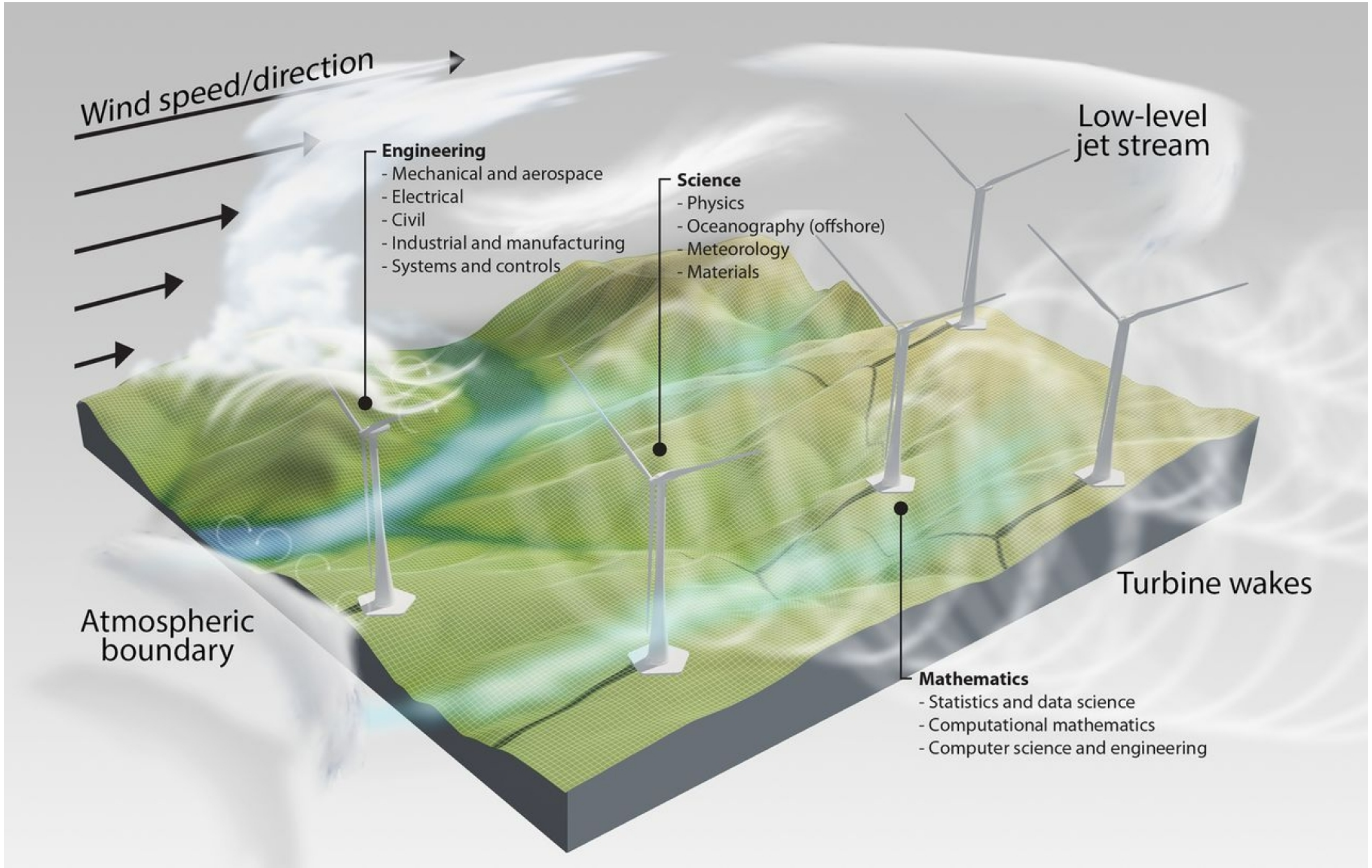
Source: Cleanpower.org

U.S. Population Density and Electric Transmission



Source: DOE-EIA

Challenges/Opportunities



Source: Science 2019, *Grand Challenges in the Science of Wind Energy*

Science Challenges in Wind Energy Research

1. Improved understanding of atmospheric and wind power plant flow physics

2. **Aerodynamics, structural dynamics, and offshore wind hydrodynamics of enlarged wind turbines**

3. Systems science for integration of wind power plants into the future electricity grid

Large Rotors

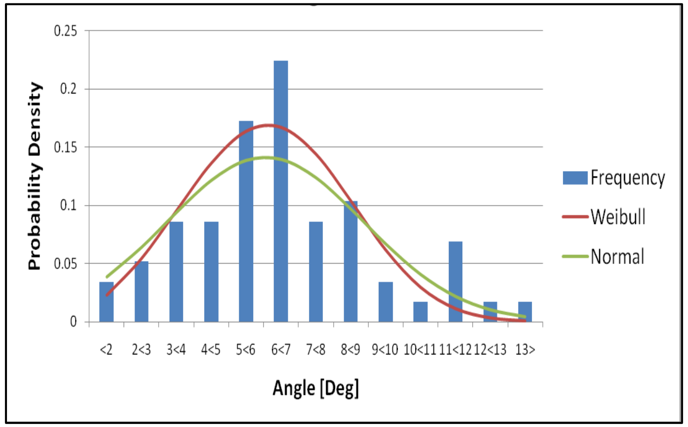
Substantial reductions in the cost of wind energy have come from large increases in rotor size

Performance: Larger rotors capture substantially more energy both through a greater swept area and accessing increased wind speeds at higher altitude

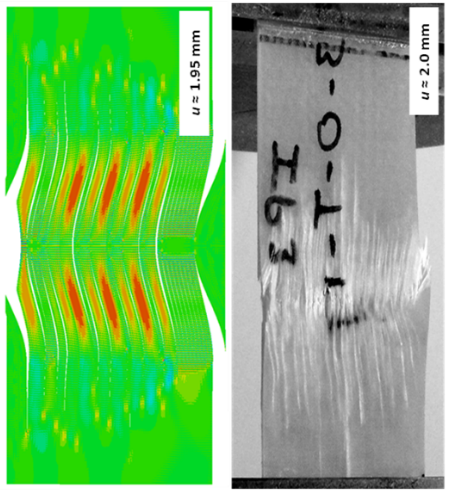
Grid Integration: Larger rotors also enable higher capacity factor wind plants, yielding less variability in power production

Deployment: Limited high wind resource sites remain, further deployment depends on developing lower wind resource sites

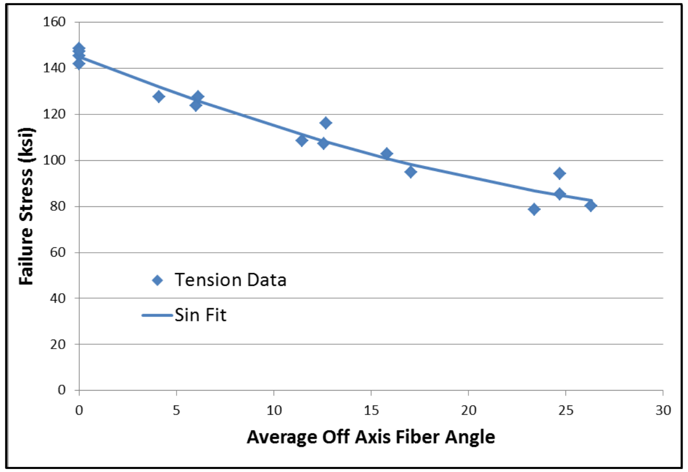
Large Rotor Challenges
Design and Manufacturing



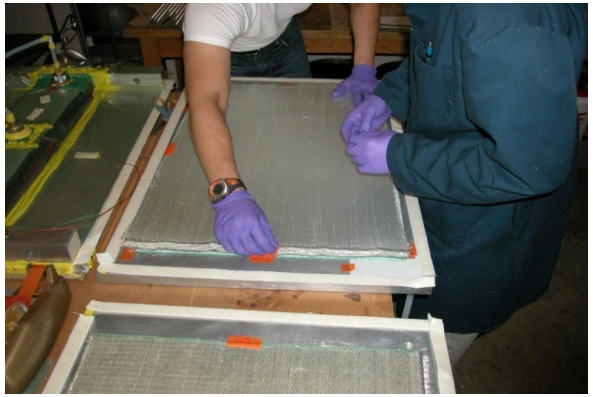
Flaw Distribution



Coupon Test

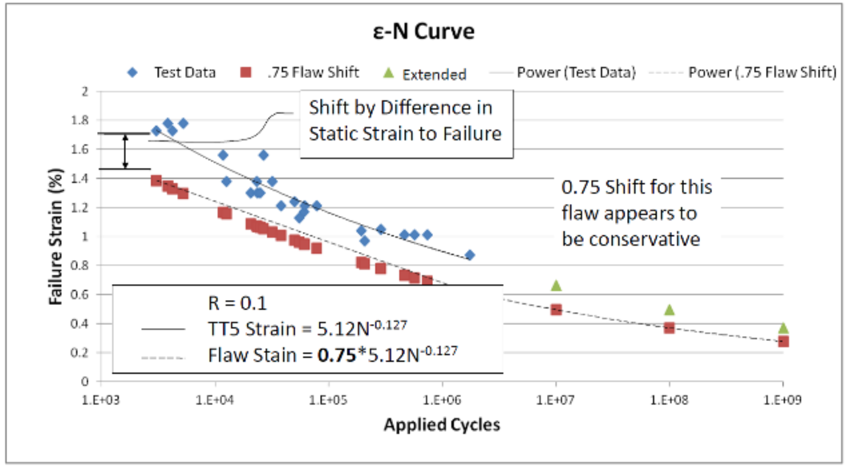


Ultimate Strength



Specimen Production

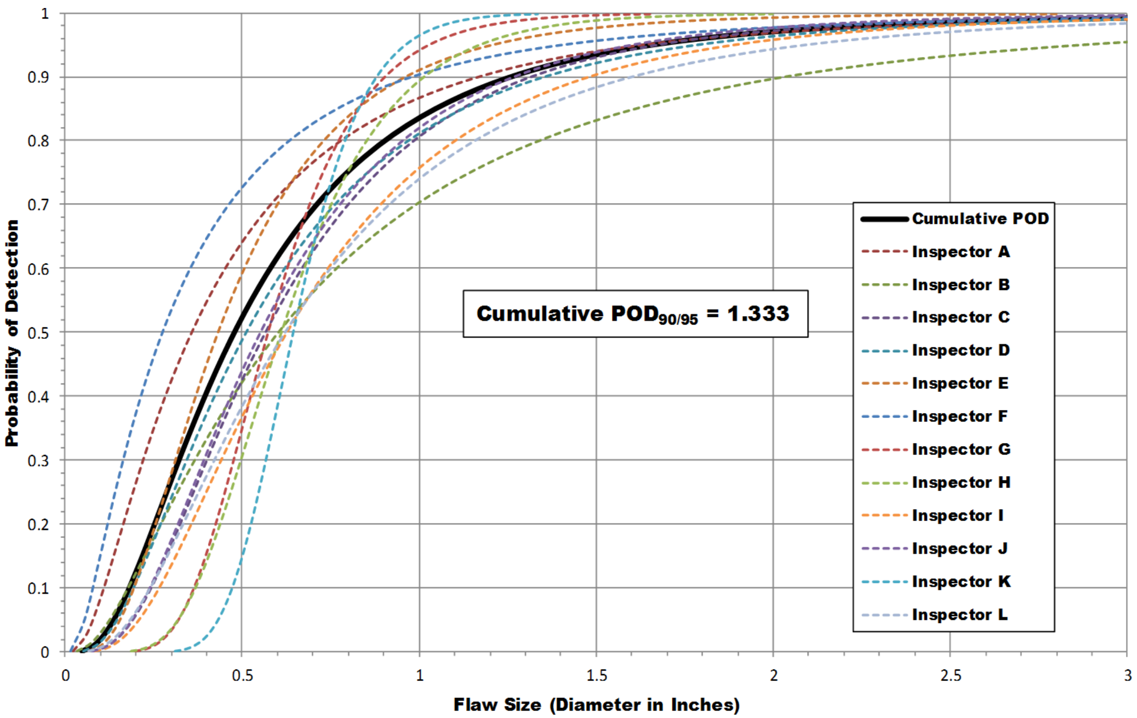
Detail/Substructure Test



Fatigue

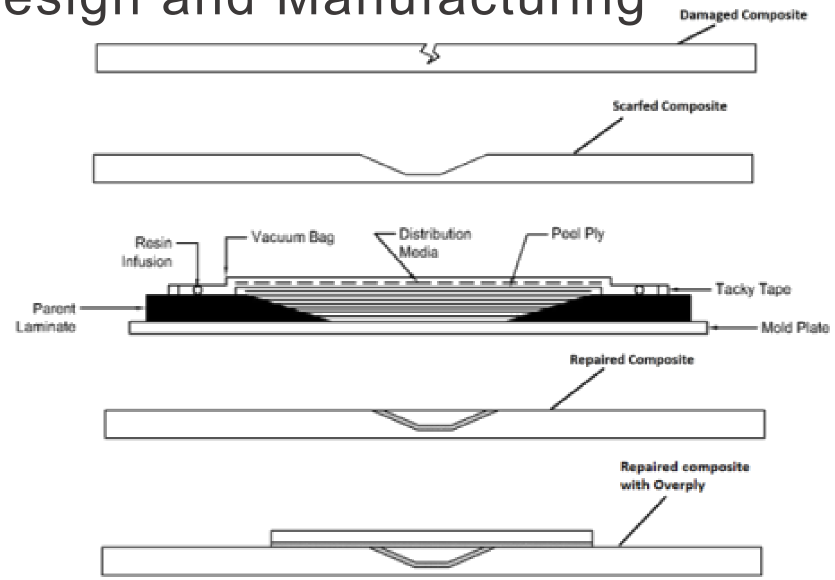
Source: Montana State

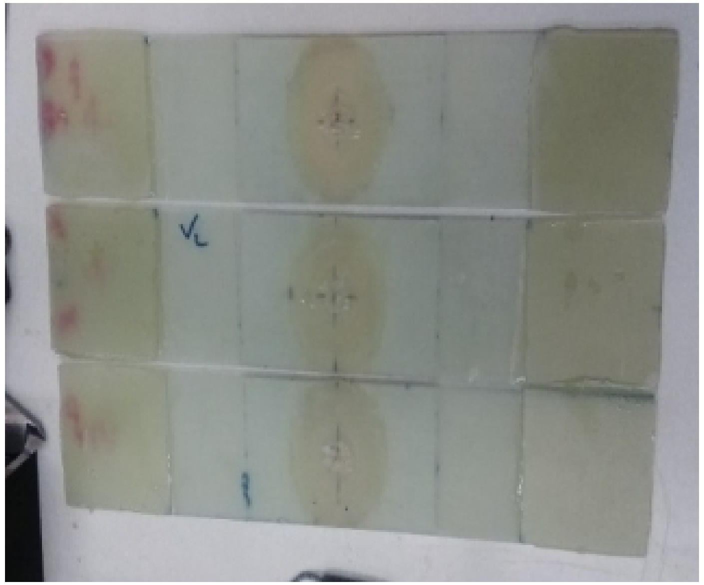
Large Rotor Challenges
Design and Manufacturing

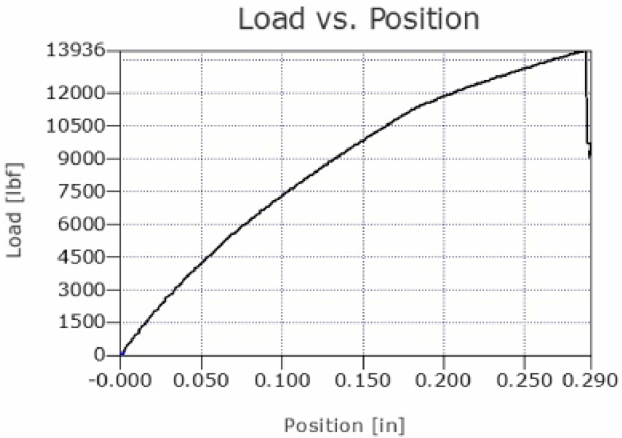


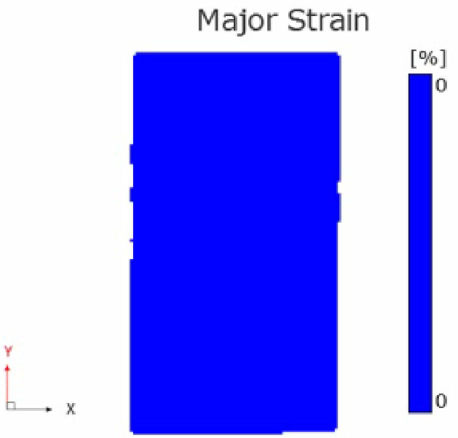
Sources: SkySpecs, ICM

Large Rotor Challenges
Design and Manufacturing



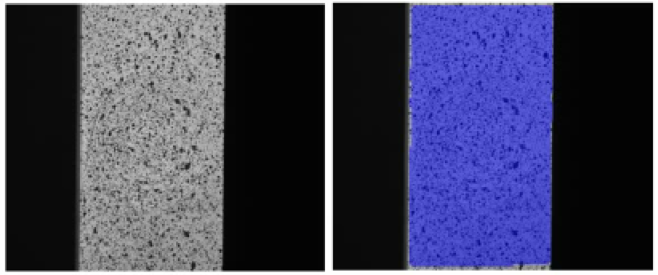






4050_5(Damaged_Unrepaired).dap		
Uniaxial Tension		
Test Rate	0.06 in/min	
Stage from to	0 -> 0	
Disp	-9.604	in
Load Y	0.000	lbf
Min Strain	0.000	%
Max Strain	0.000	%
Average Strain	0.000	%

Test Data



Left Camera

with Overlay

MONTANA STATE UNIVERSITY

Montana State University
Mechanical Engineering

10/13/2016
4050_7

gom ARAMIS

Source: Montana State

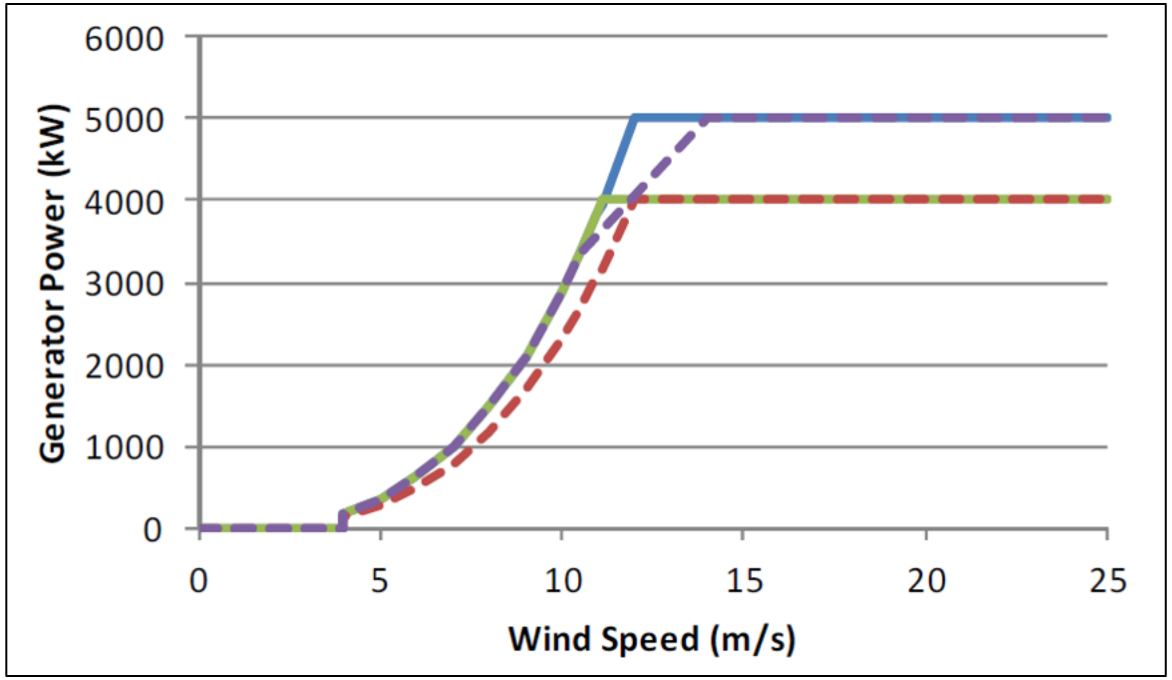
Large Rotor Challenges
Transportation

Width limited to ~4.75m

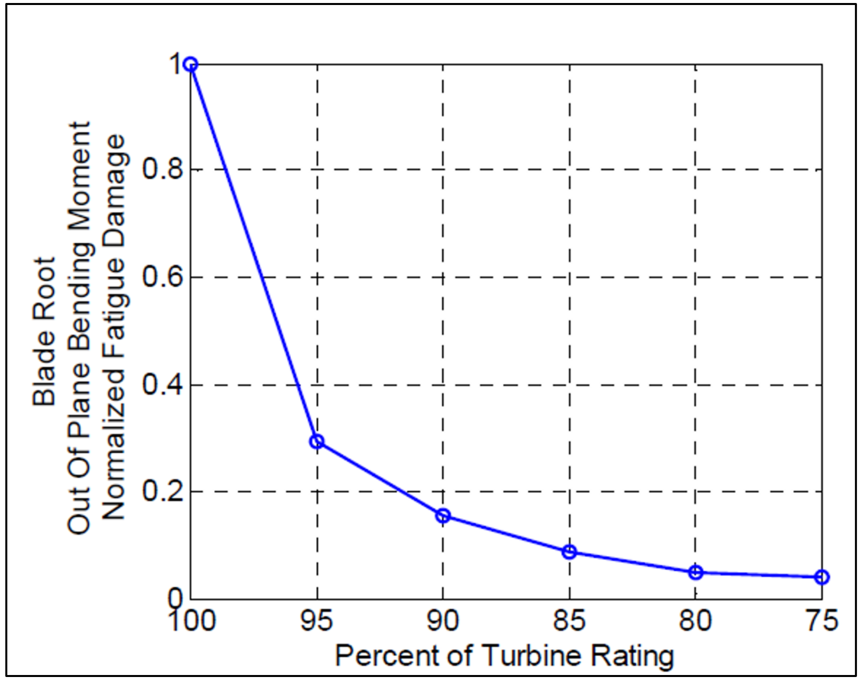
Length limited to ~80m

Source: LM Windpower

Large Rotor Challenges
Operations

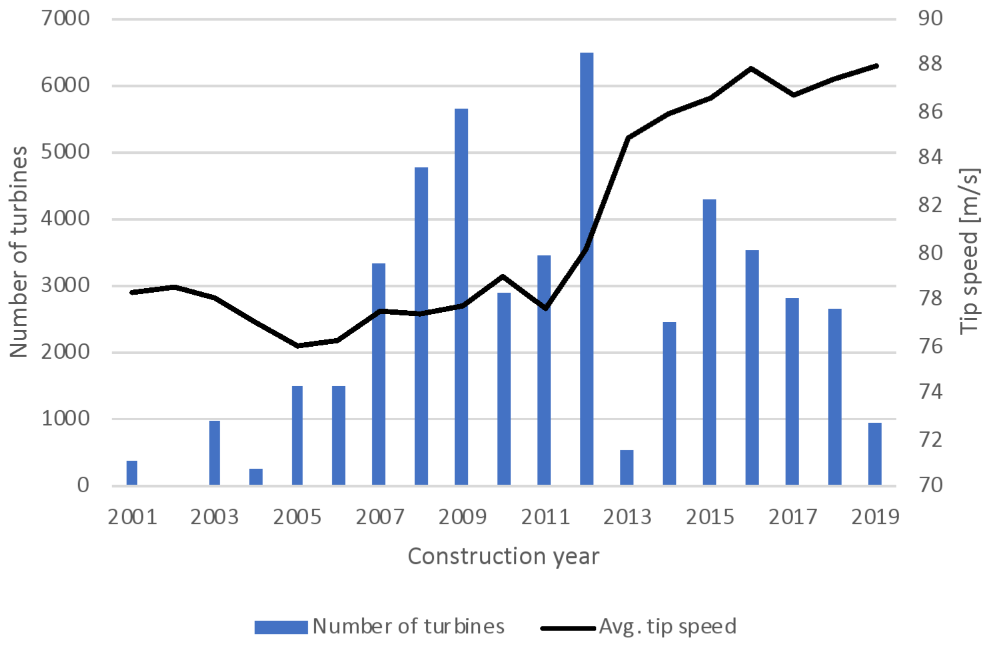


Operational Strategies

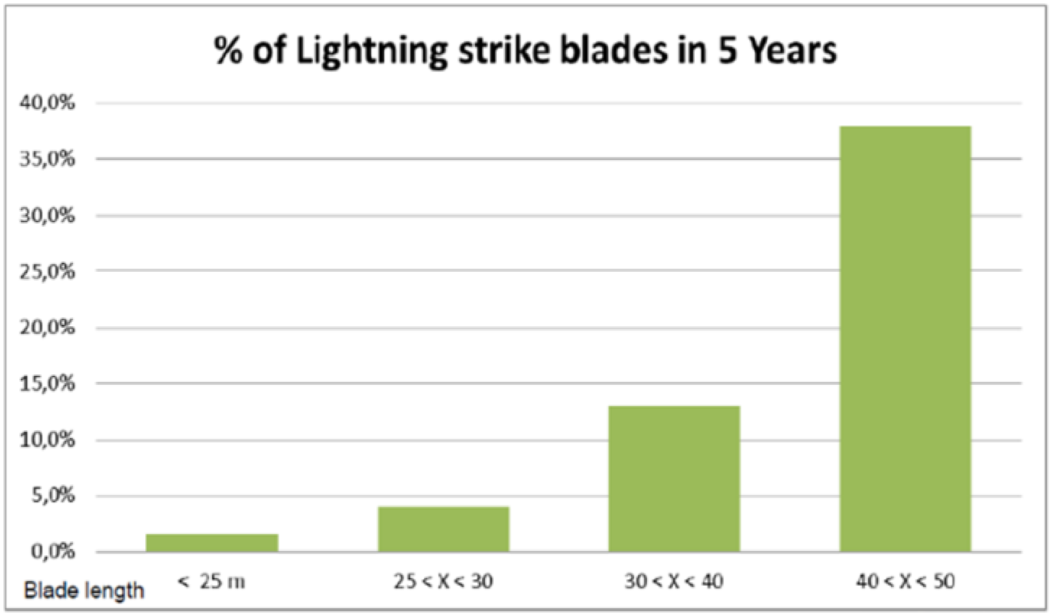


Fatigue Accumulation (Damage Growth)

Large Rotor Challenges
Environmental



Historical Rotor Tip Speeds

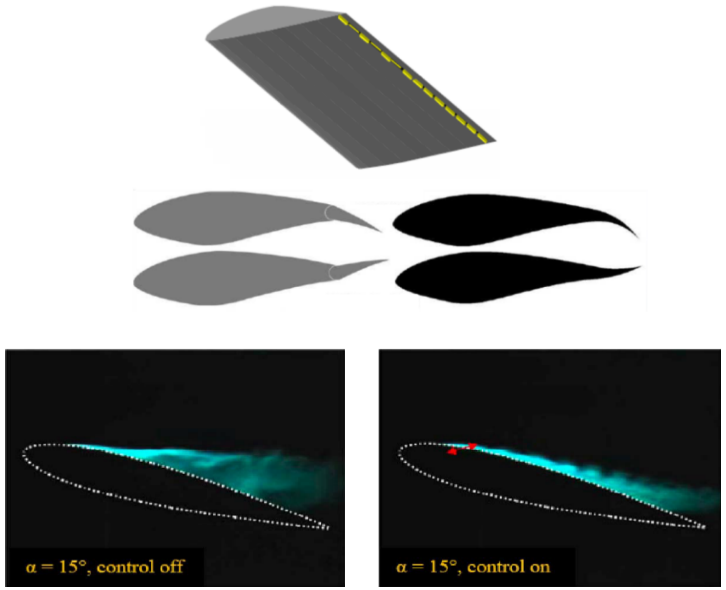


Lightning Strikes by Blade Length, Vestas (2014)

Erosion ∝ $V^{6.7}$

Strike Frequency ∝ H^4

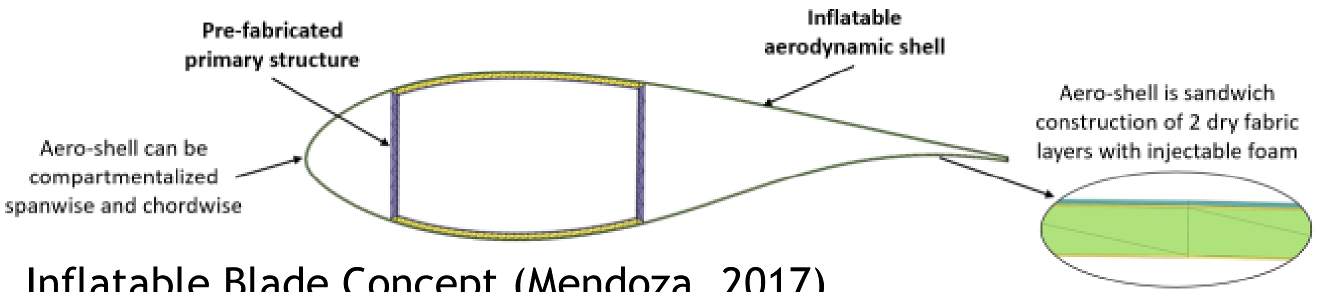
Advanced Concepts



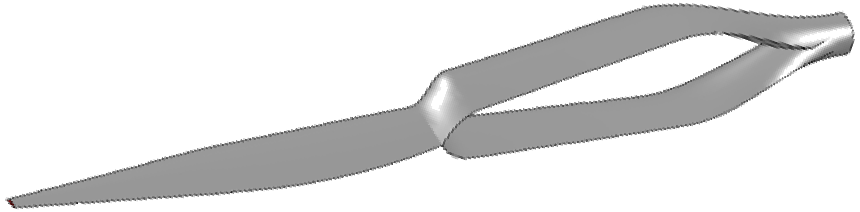
Trailing edge tabs and flaps, top, and synthetic jets, bottom (UC-Davis, 2008)

Downwind Rotors

On-Site Manufacturing (TPI Composites, 2003)



Inflatable Blade Concept (Mendoza, 2017)



Bi-Wing Concept (Chu, 2017)

Thank you