Advanced Wind Technology:

Elevated Opportunities for the South

Allie Brown

Simon Mahan

Southern Alliance for Clean Energy

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For more than 25 years the Southern Alliance for Clean Energy has worked to promote responsible energy choices that create global warming solutions and ensure clean, safe and healthy communities throughout the Southeast.

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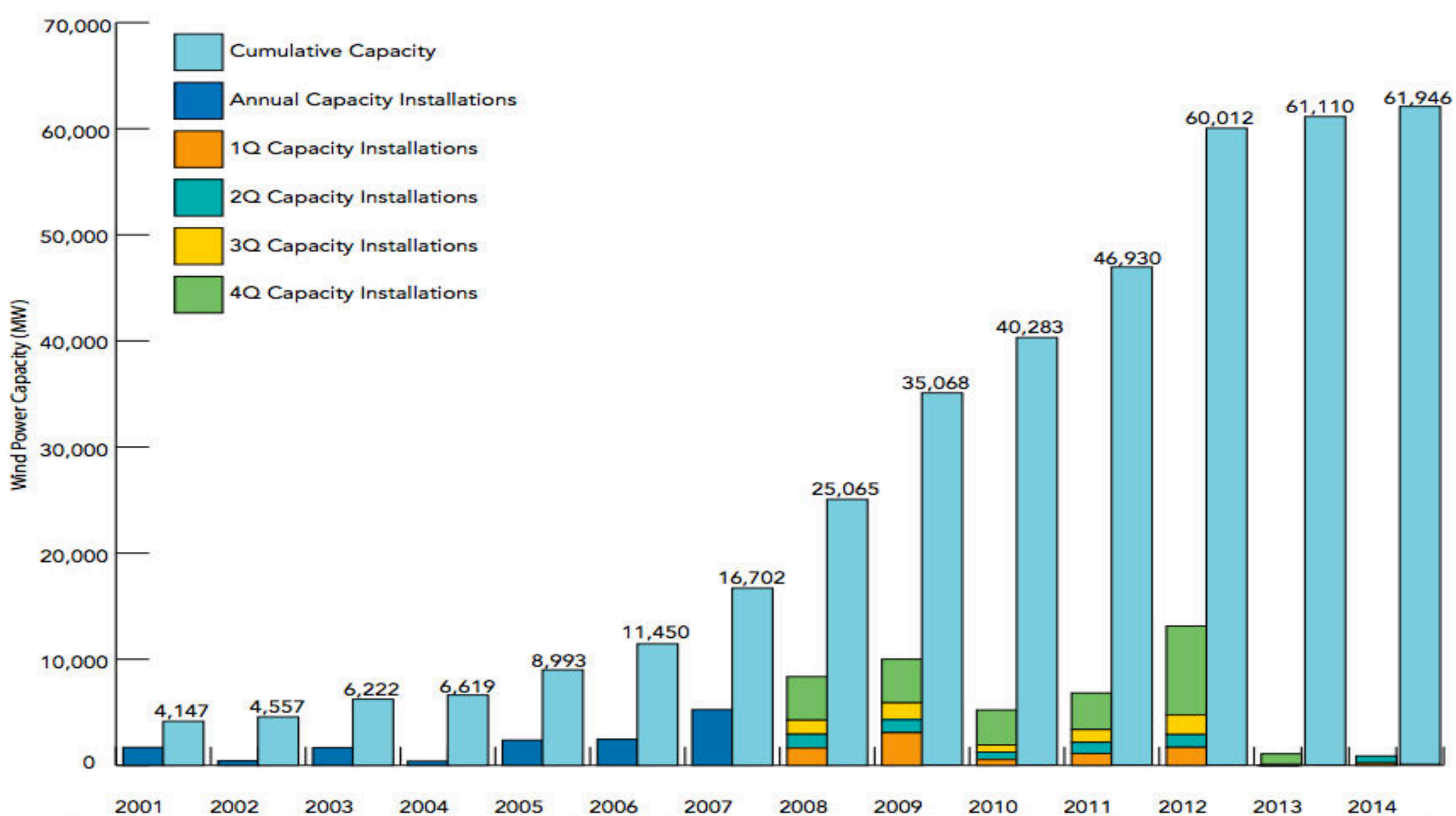
U.S. Wind Energy Overview

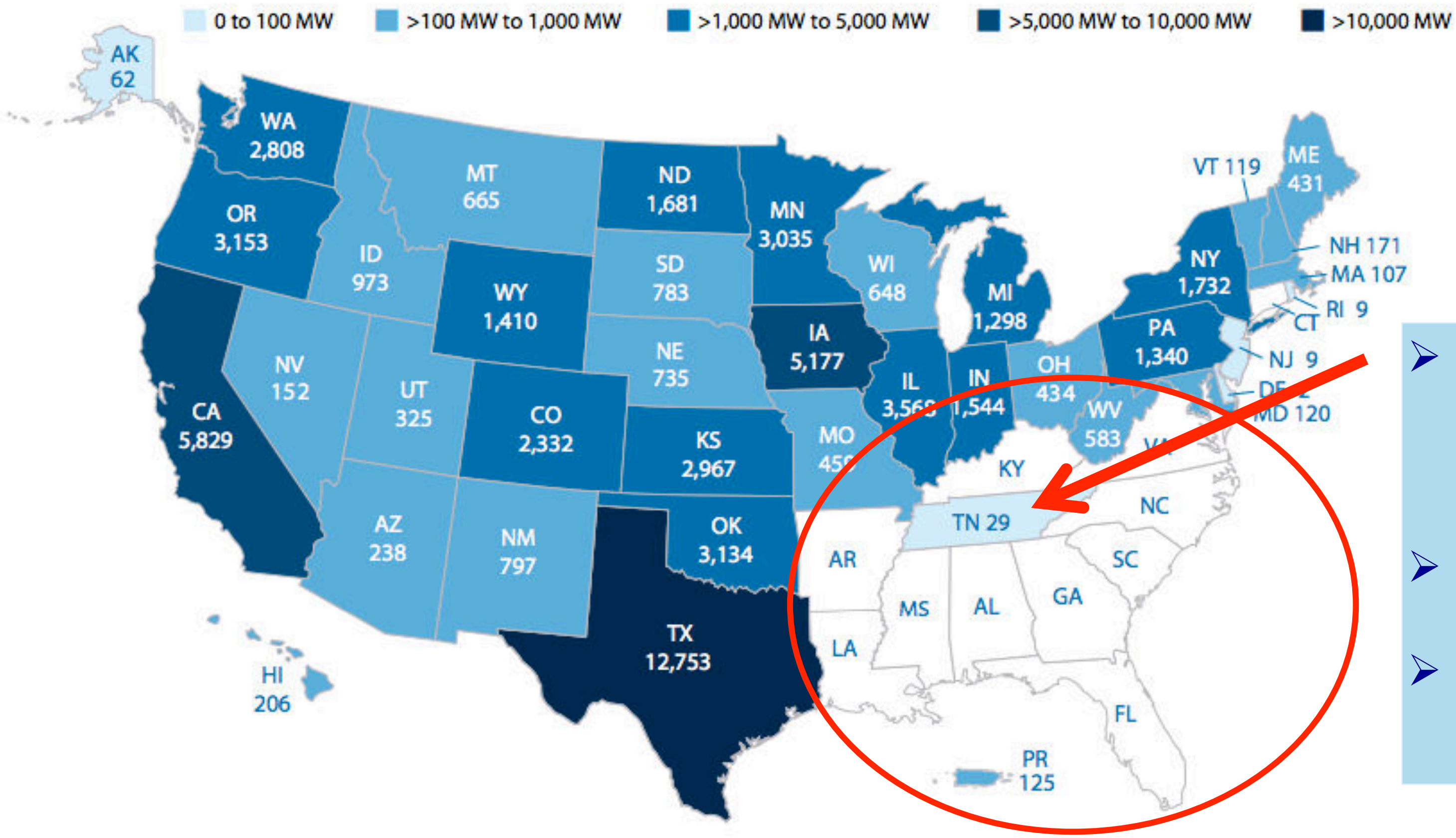
- 62,000 MW of wind energy installed (over 16 million homes)
- 14,000 MW under construction
- 5th largest electricity source in the U.S.
- 550 manufacturing facilities across 44 states
- Approximately 75,000 U.S. jobs

U.S. Wind Energy Overview



Credit: American Wind Energy, “U.S. Wind Industry Second Quarter 2014 Market Report”

Wind Energy in the South: Installation

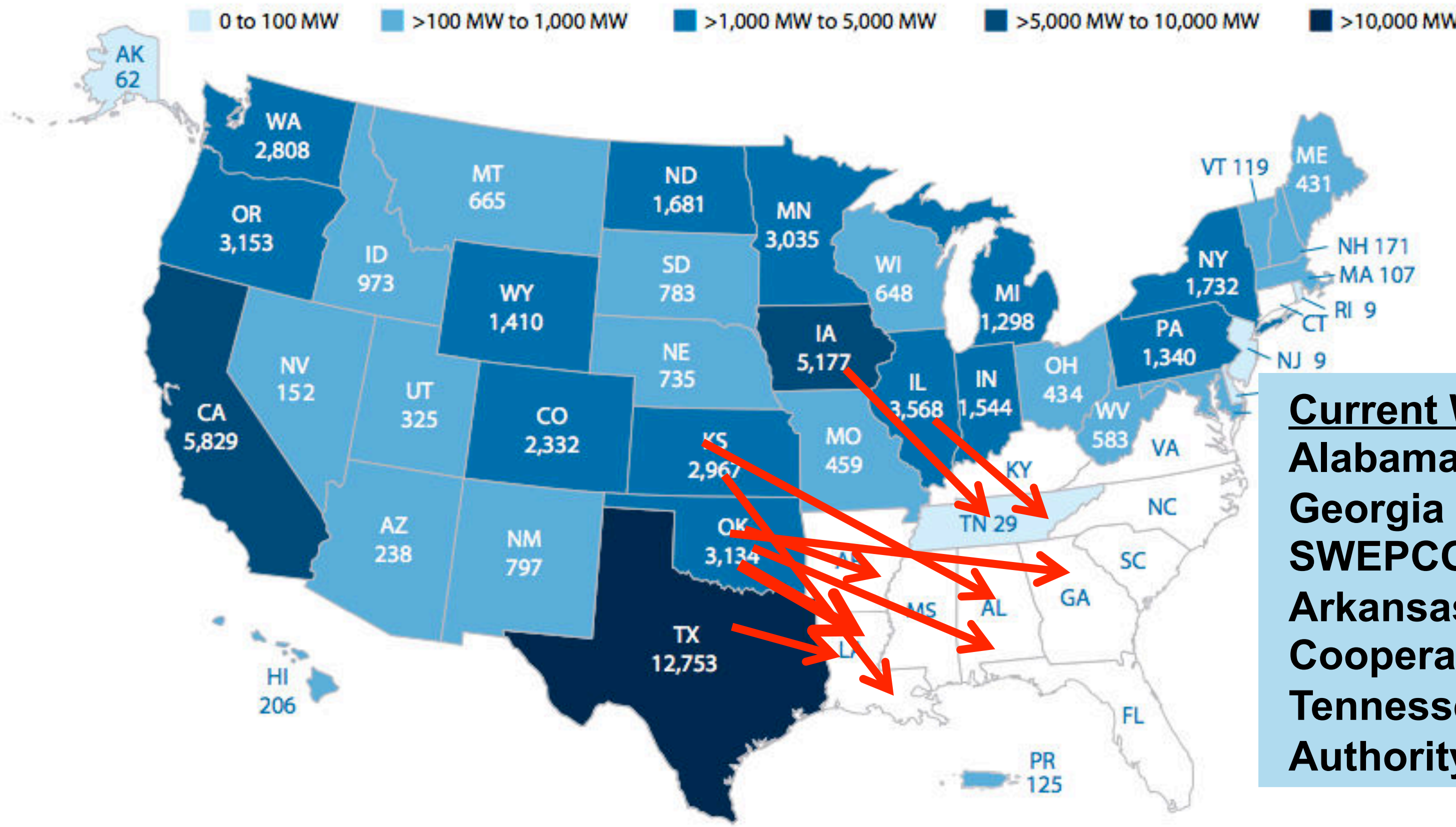


- **[Buffalo Mountain Wind Farm]—near Oak Ridge, Tennessee**
- **27 MW project (TVA owned)**
- **Powers 3,400 homes a year**

Credit: American Wind Energy, "U.S. Wind Industry Second Quarter 2014 Market Report"

Wind Energy in the South: Transmission

Over 2,600 MW of power purchase agreements (PPAs) for the Southeast already for wind energy



Current Wind PPAs:
Alabama Power
Georgia Power
SWEPCO (Louisiana)
Arkansas Electric Cooperative
Tennessee Valley Authority

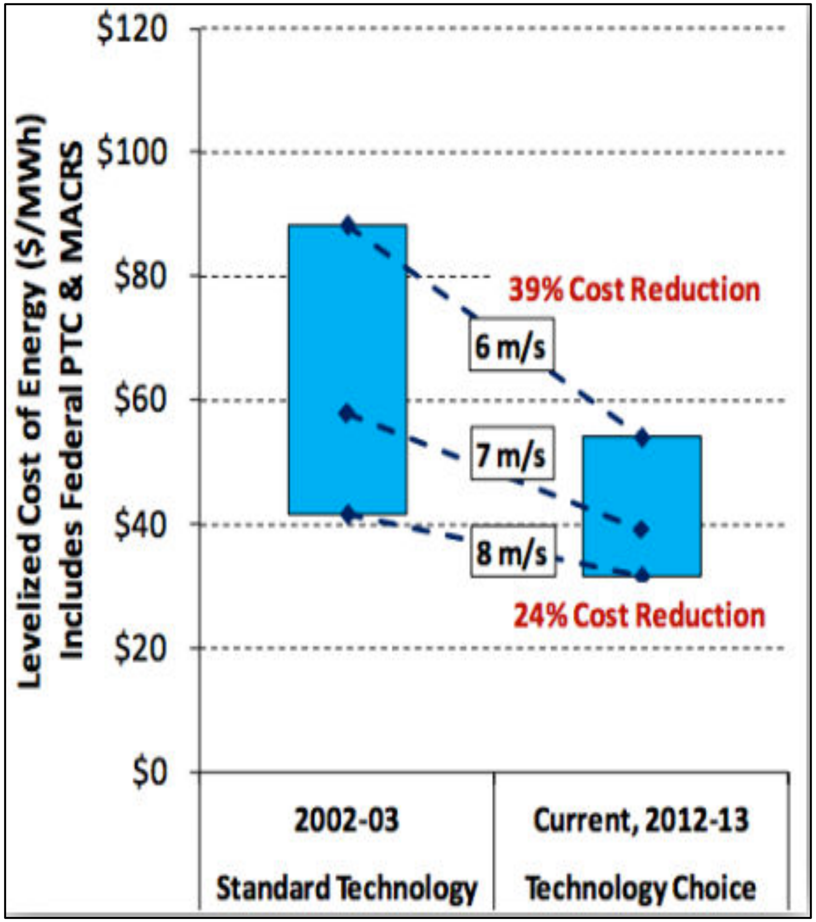
Advanced Turbine Technology: Improved Turbines

- Evolved quickly over the past 5 years
- Taller towers and longer blades
- Hub heights up to 140 meters are available
- Longer blades capture more wind, harness slower wind speeds
- As a result, the turbines are able to capture more wind and thus achieve higher capacity factors (~40%)
- Advanced turbine technology makes the Southeast the next frontier for wind energy development

Credit: National Renewable Energy Laboratory

Advanced Turbine Technology: Reduced Costs

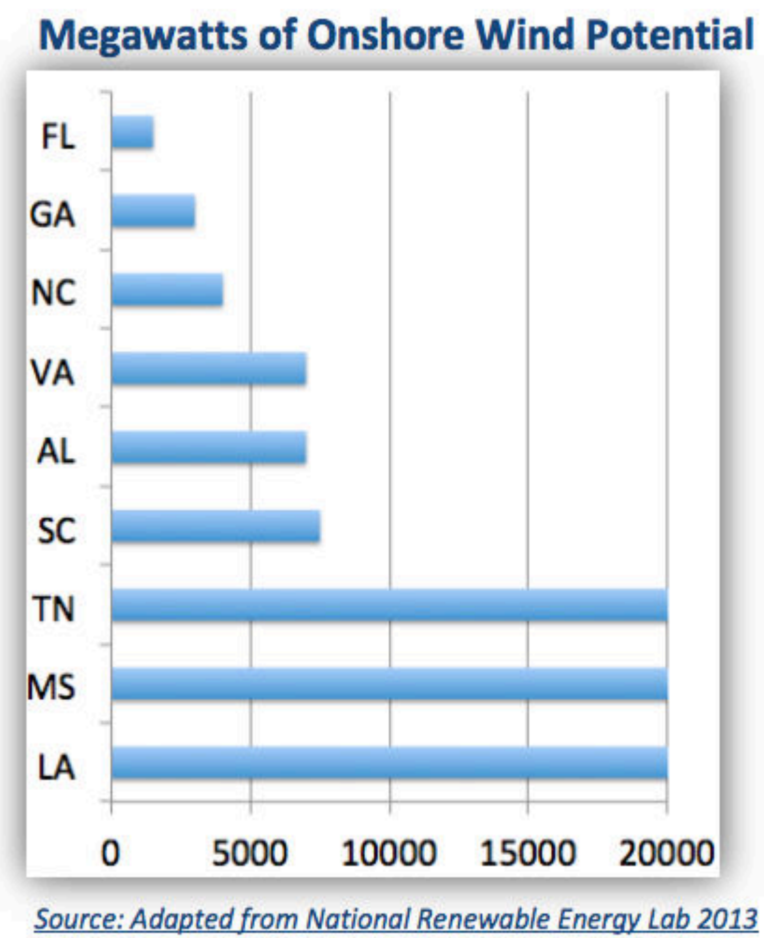
- Advanced technology has increased average wind speeds which lower cost
- Land-based wind energy is now one of the lowest cost forms of new power generation in the country
- Costs have declined by 39% over the past decade
- Cost in the Southeast still higher than the Midwest, but continues to drop as technology improves
- Costs will continue to drop



Credit: National Renewable Energy Laboratory, 2013

Advanced Turbine Technology: Expanded Potential

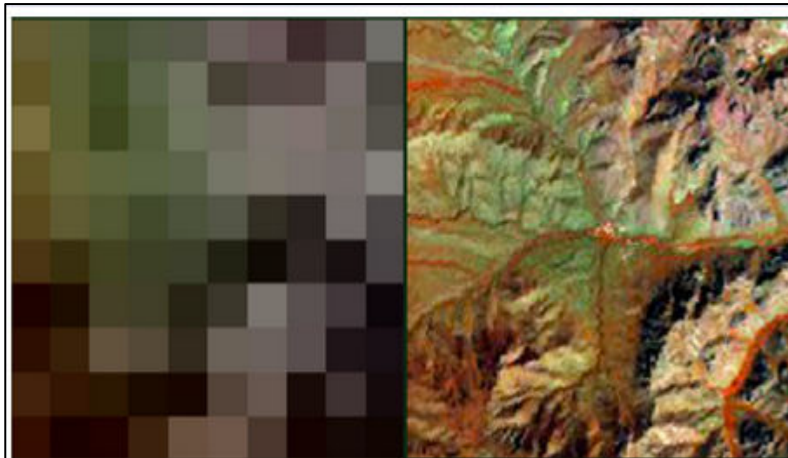
- Louisiana, Mississippi, and Tennessee all contain over 25,000 megawatts of potential
- With new turbines, the region contains over 134,000 megawatts (MW) of wind potential—about half as much of total installed electric utility capacity!
- With improved turbines and reduced costs, wind farms now make economic sense in all states across the South.
- Projects proposed in almost every state



Credit: National Renewable Energy Laboratory

Resource Assessment

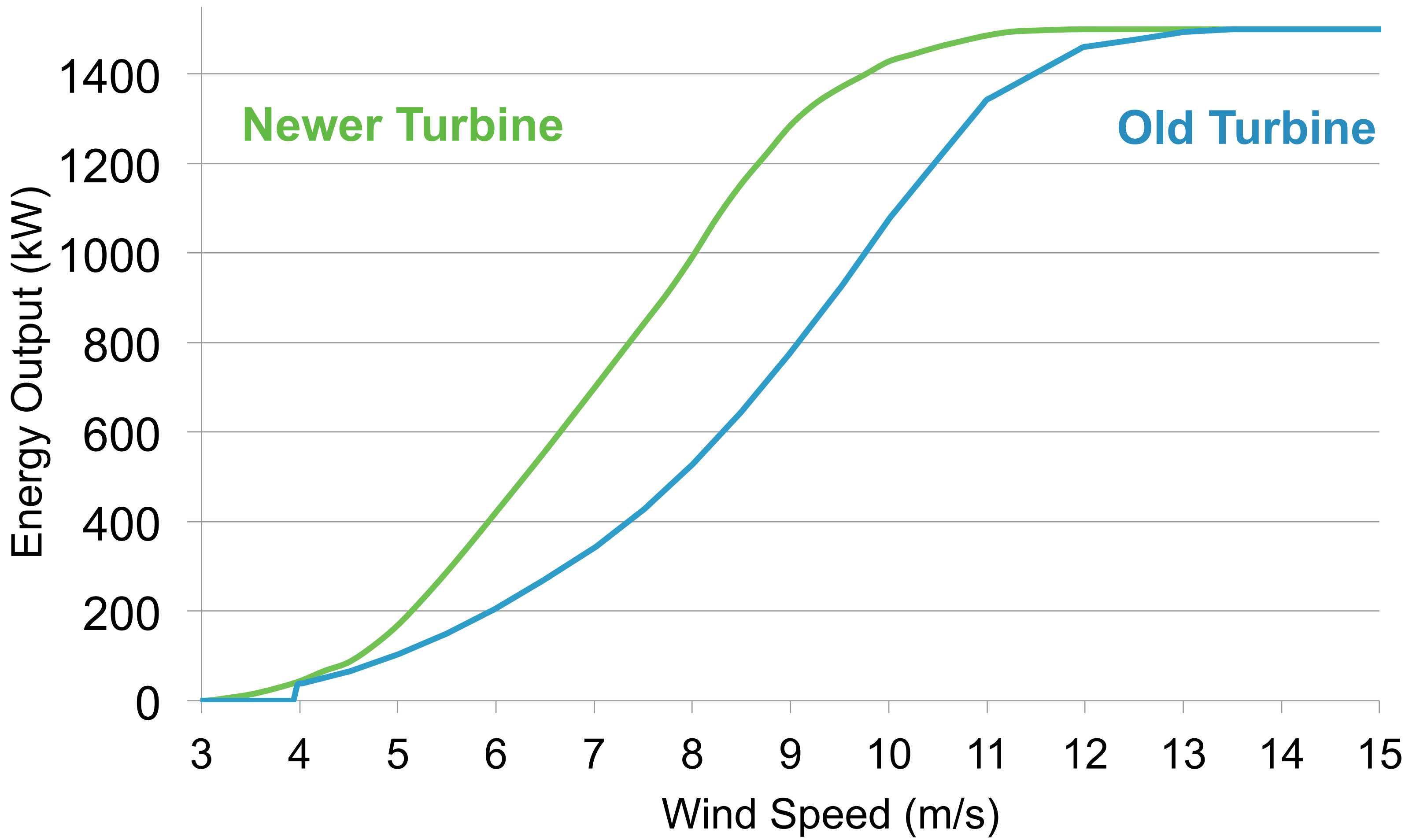
- Expanded potential In South highlights the need for updated wind resource assessment maps
- Coarse wind assessment maps are often not accurate enough to identify ridge top wind resources
- Maps only assess turbines at lower hub heights *(80 meters and lower)*
- Areas characterized as “low wind speed” could actually be suitable for development
- 5 case studies



Map Spatial Resolution Matters
Left: 500-meter resolution
Right: 30-meter resolution
A 2.5-kilometer resolution would appear fuzzier – and miss a whole mountain.

Credit: American Museum of Natural History

What is a Power Curve?



How important is wind speed?

Capacity Factors by Wind Speed

	5 m/s	6 m/s	7 m/s	8 m/s
Older Turbine	7%	14%	23%	35%
Newer Turbine	11%	28%	46%	66%

35%

Output 64% greater

Output 100% greater

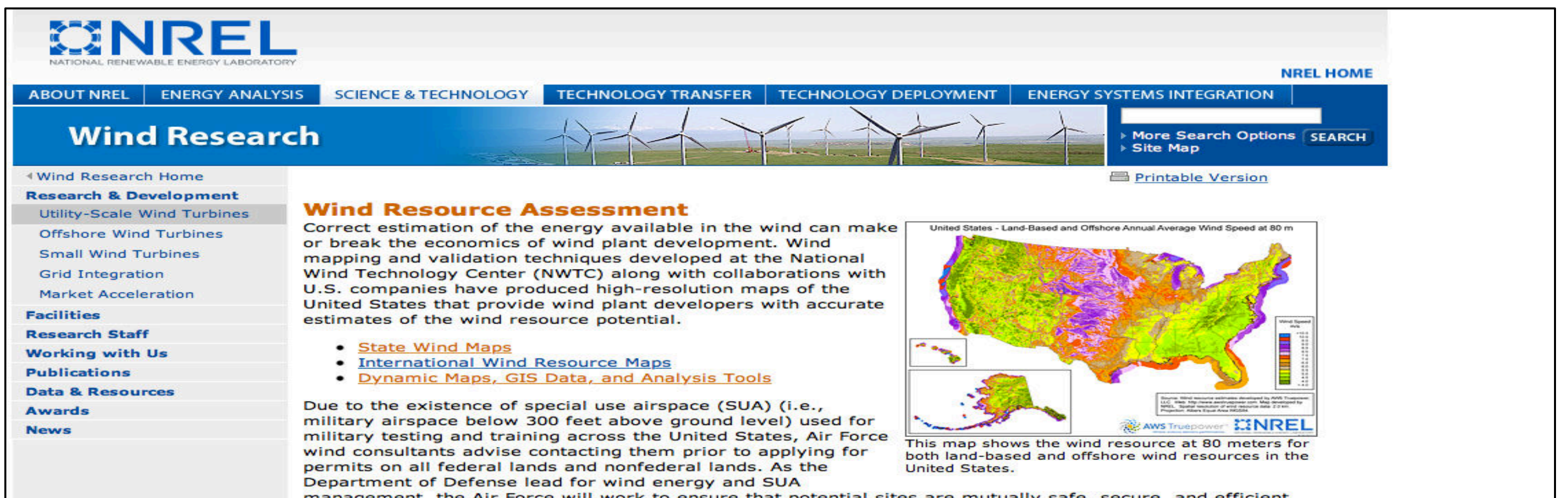
Output 100% greater

Output 150% greater

- Newer turbines ~2x better in same wind regime
- New turbines can perform roughly same with 1.5 m/s slower wind speeds
- Turbines continue to improve

Five Low Wind Case Studies

- Southeast ready for wind energy development with new turbine technology, but resource maps do not always reflect this potential
- Compare wind speeds from NREL's popular resource assessment maps with available data/information on particular wind turbines sites
- Maps often used to initially assess wind farm sites and easily accessed by the public
- In most case studies, actual performance of the wind turbines is much greater than can be determined by looking solely at the wind resource maps



Low Wind Speed Case Studies: Buffalo Mountain Wind Farm

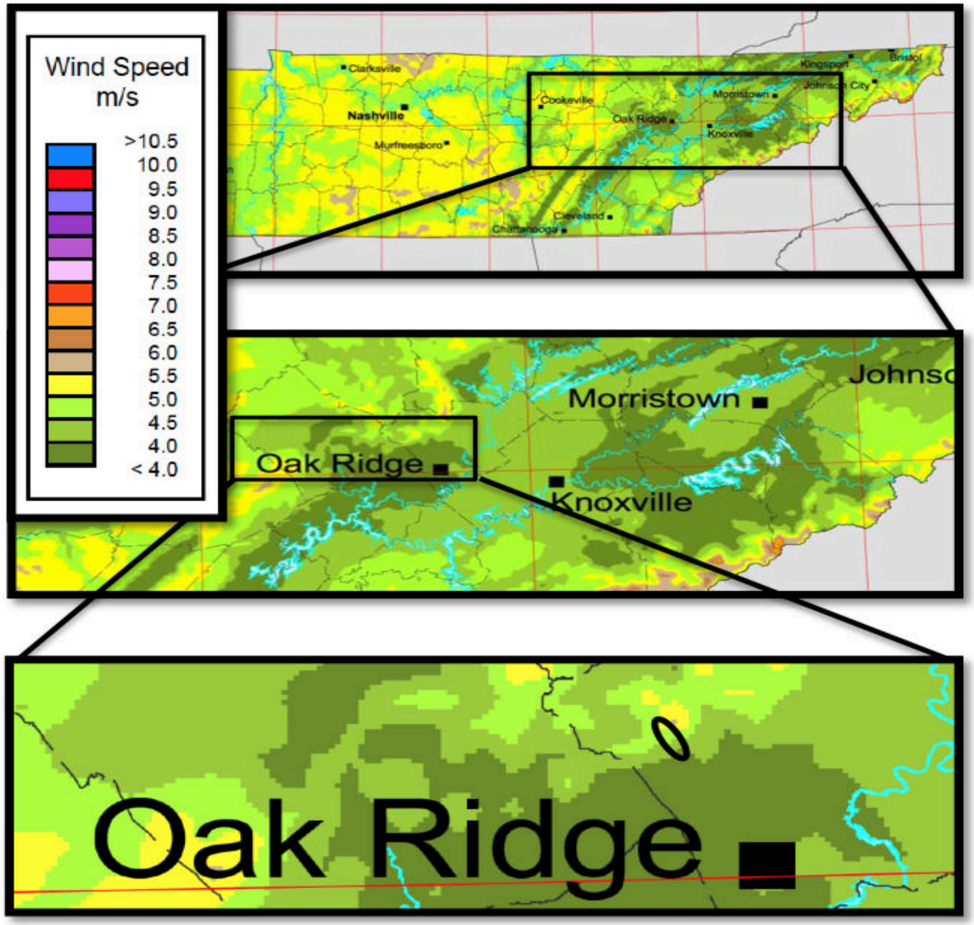
- Buffalo Mountain Wind Farm in Oak Ridge, Tennessee
- Southeast's first and currently only large-scale wind farm
- TVA began project in 2000 with three turbines
- Developer Invenergy installed 15 additional turbines in 2004
- 27 MW wind farm (serves TVA)
- Powers approximately 3,400 homes a year
- Success of wind farm contrary to NREL 80-meter map

Credit: NREL (Buffalo Mountain Wind Project, Tennessee)

Low Wind Speed Case Studies: Buffalo Mountain Wind Farm

- NREL 80 meter map (~260 feet) state by state, 2010
- Approximately same hub height as Buffalo Mountain's wind turbines
- Difficult to gauge, but best prediction from the map is **4.0-5.0 m/s** (8.9-11.2 mph)

Figure 1. Tennessee Average Annual Wind Speeds (80 Meters)

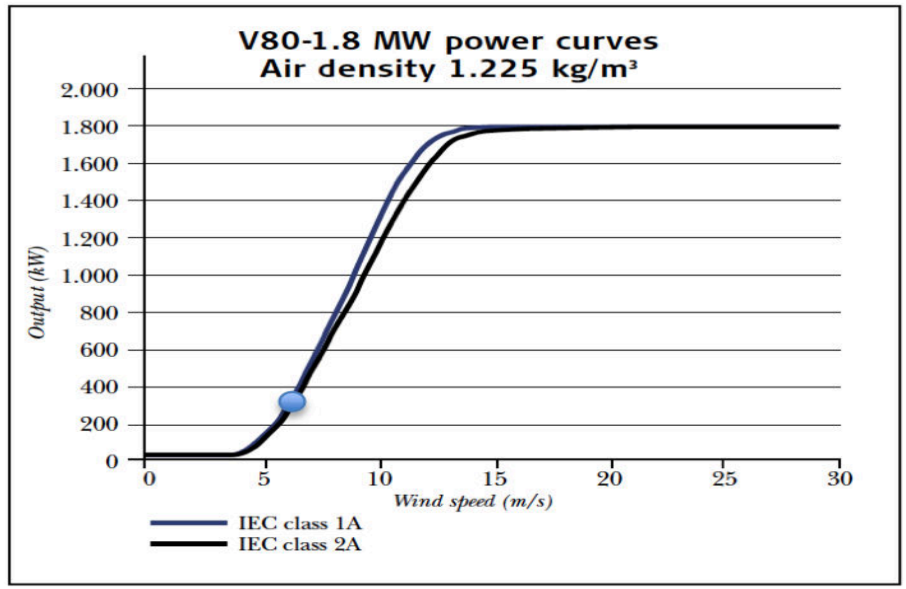


Source: National Renewable Energy Lab 2010

Low Wind Speed Case Studies: Buffalo Mountain Wind Farm

- Data from the actual wind farm production can help us to more accurately determine the average wind speed:
- In 2012, the wind farm generated 48,000 megawatt hours of electricity from the 15 turbines
- Each turbine is 1.8 megawatts
- Capacity factor of approximately 20%
- Average hourly output is 360 kilowatts (20% of 1.8 megawatts)

Figure 2. Vestas V80-1.8 Power Curve



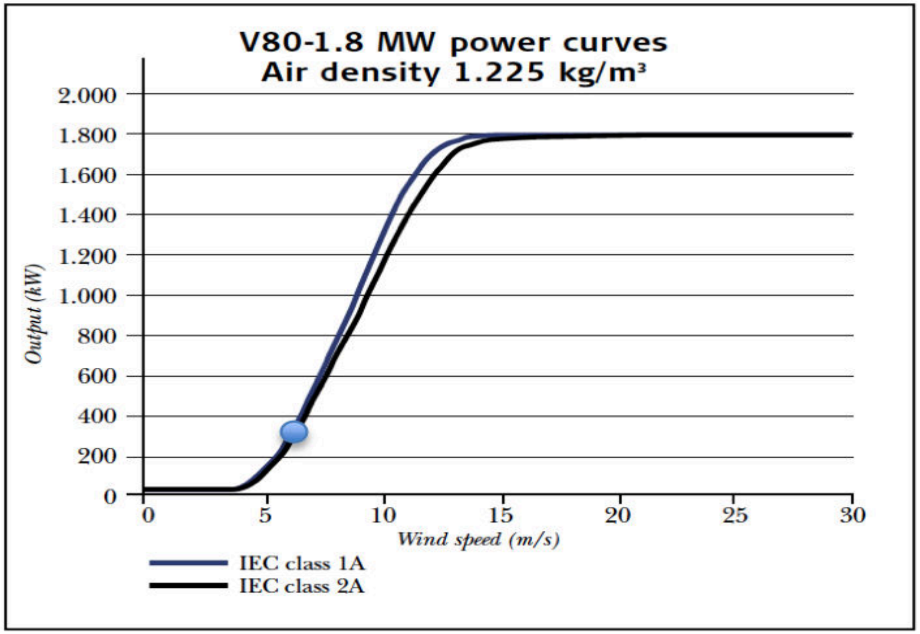
Source: Vestas V80-1.8 Factsheet

- **Based on the turbine power curve above, the site may achieve an average of 6 m/s (13.4 mph) wind speeds**

Low Wind Speed Case Studies: Buffalo Mountain Wind Farm

- NREL: 4.0 m/s-5.0 m/s (8.9-11.2 mph)would place the wind farm at a 100 kilowatt per hour output
- Capacity factor of only 5-10%
- Actual output at least double what the NREL 80 meter map predicts

Figure 2. Vestas V80-1.8 Power Curve



Source: Vestas V80-1.8 Factsheet

Low Wind Speed Case Studies: NBC Field's Point Wind Project

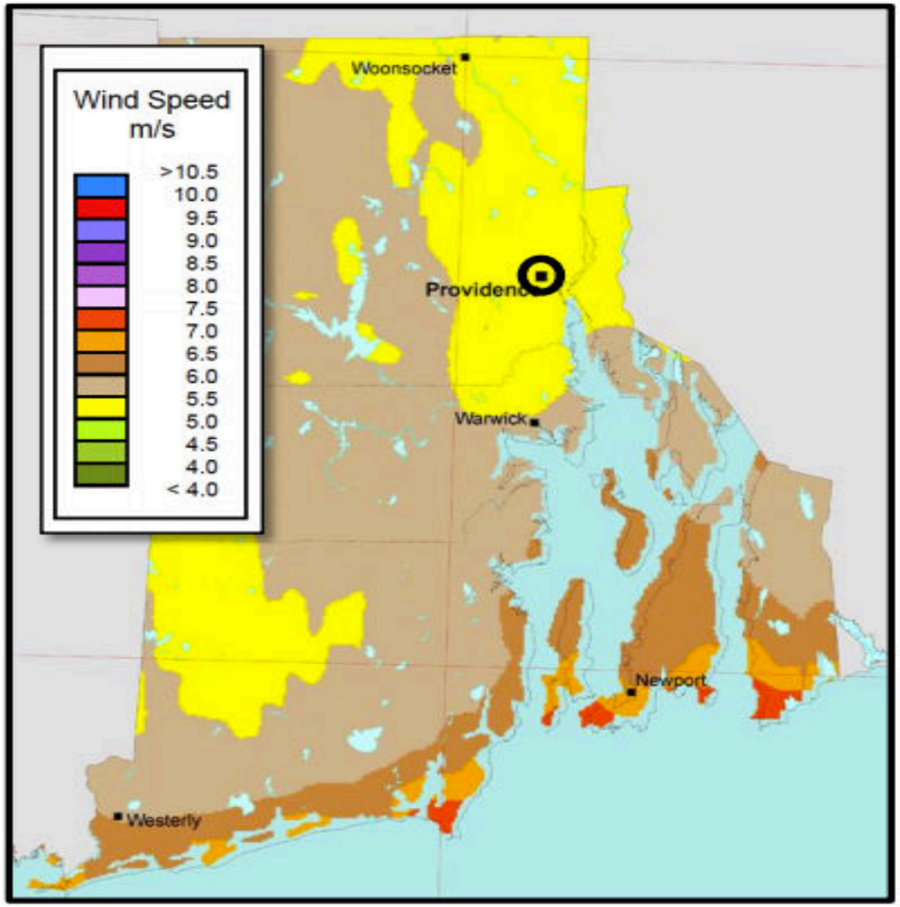
- Narragansett Bay Commission's (NBC) Fields Point wastewater treatment plant in Providence, Rhode Island
- 3 large scale turbines (each 1.5 MW) installed in 2012
- Produced 6,700 megawatt hours of electricity in first year of operation

Credit: Mary Murphy, The Providence Journal

Low Wind Speed Case Studies: NBC Field's Point Wind Project

- 5 m/s (11.2 mph) wind speed at 80 meter hub height

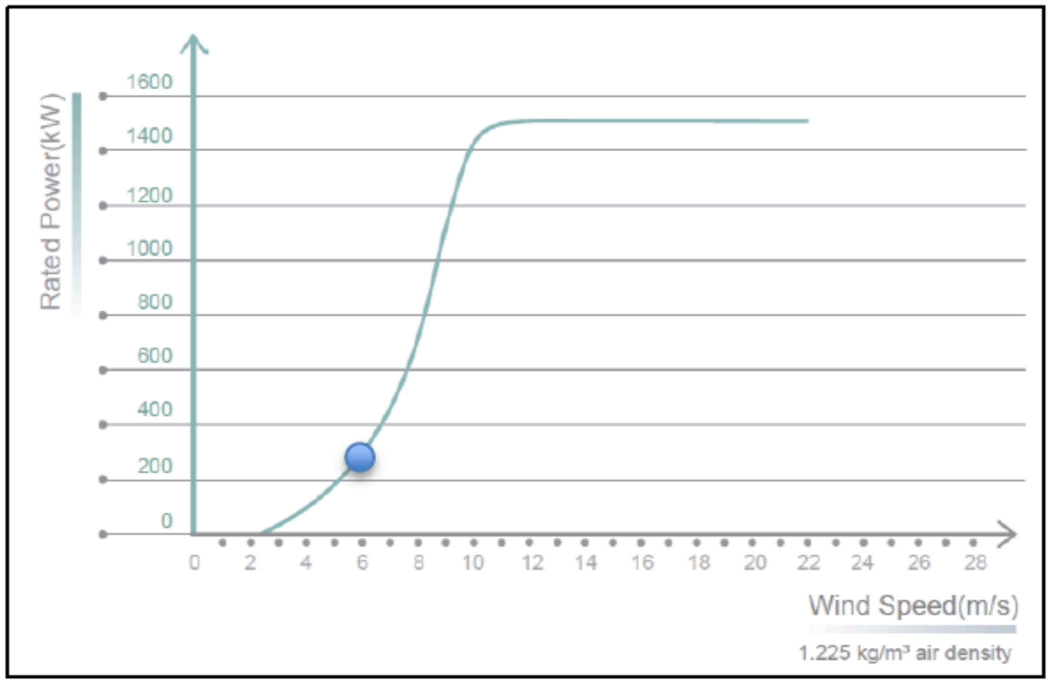
Figure 1. Rhode Island Annual Wind Speeds (80 Meters)



Low Wind Speed Case Studies: NBC Field's Point Wind Project

- Data from the actual wind turbine production can help us to more accurately determine the average wind speed:
- 6,700 megawatt hours in first year
- Each turbine is 1.5 megawatts
- Capacity factor of approximately 17%
- Average hourly output is 255 kilowatts (17% of 1.5 megawatts)

Figure 2. Goldwind America GW 82/1500 Power Curve



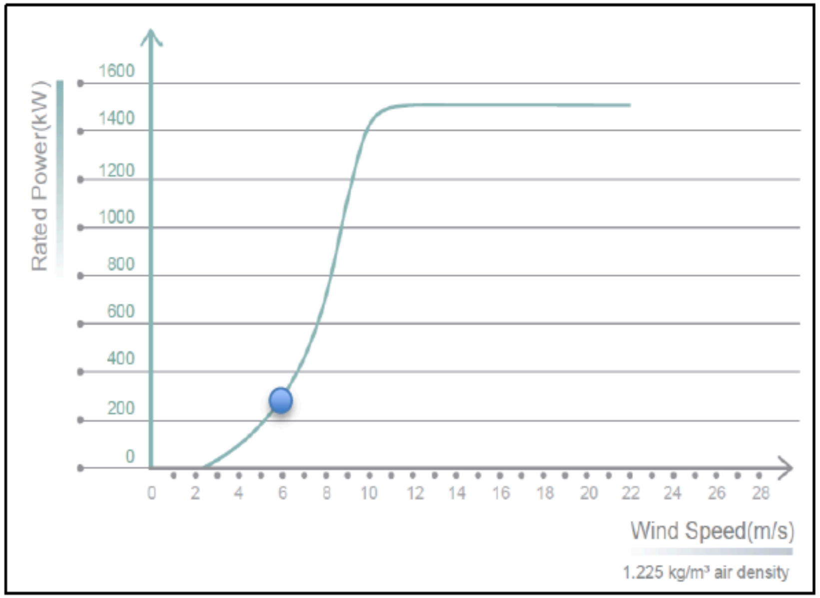
Source: Goldwind America 1,5 MW Product Brochure 2013

Based on the turbine power curve above, the site may achieve an average of 6 m/s (13.4 mph) wind speeds

Low Wind Speed Case Studies: NBC Field's Point Wind Project

- NREL: 5.0 m/s (11.2 mph) would place the wind project at below 200 kilowatt per hour output
- Capacity factor of only 12%
- Actual output at the NBC Field's Point Wind Farm is at least 40% better than what would be expected using the NREL map with the estimated wind speed.

Figure 2. Goldwind America GW 82/1500 Power Curve



Source: Goldwind America 1,5 MW Product Brochure 2013

Low Wind Speed Case Studies: Puerto Rico Wind Farm Projects

Finca de Viento Santa Isabel (Santa Isabel) Wind Farm

- Began operation is 2012
- 44 wind turbines (each 2.3 megawatts)
- Total capacity: 101.2 MW
- Pattern Energy

Credit: Pattern Energy (Finca de Viento Santa Isabel Wind Project, Puerto Rico)

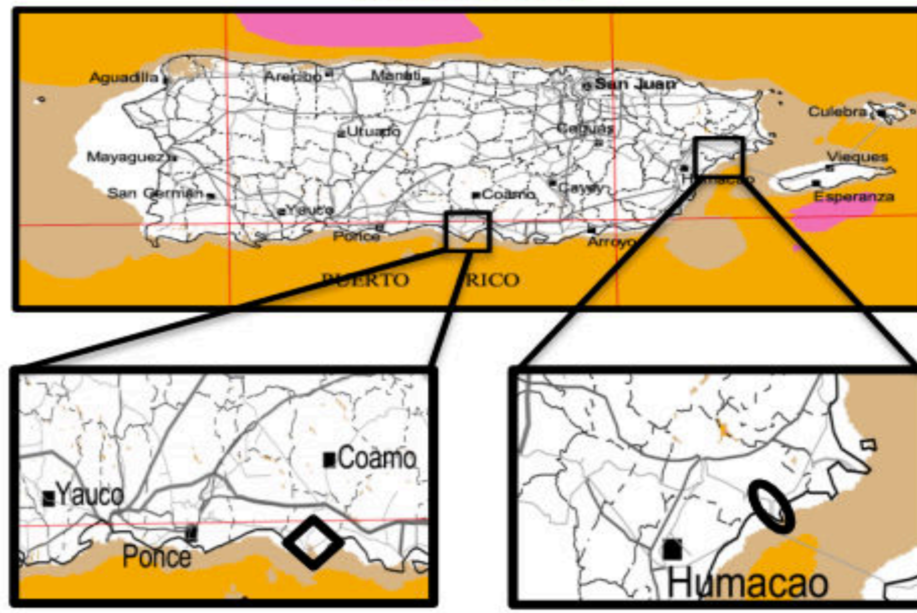
Punta de Lima Wind Farm

- Began operation in April 2013
- 13 Vestas 1.8 MW turbines
- Total capacity: 23.4 MW

Low Wind Speed Case Studies: Puerto Rico Wind Farm Projects

- 2007 NREL 50 meter (164 feet) map of Puerto Rico
- Diamond: Santa Isabel
- Oval: Punta de Lima
- Map suggests these wind farms would be undevelopable with a “poor” to “marginal” wind resource

Figure 1. Puerto Rico and the Virgin Islands 50-Meter Wind Resource Map



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ^{2}	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.9	0.0 - 13.2
2	Marginal	200 - 300	5.9 - 6.8	13.2 - 15.2
3	Fair	300 - 400	6.8 - 7.5	15.2 - 16.8
4	Good	400 - 500	7.5 - 8.0	16.8 - 17.9
5	Excellent	500 - 600	8.0 - 8.5	17.9 - 19.0

[a] Wind speeds are based on a Weibull k of 2.5 at sea level.

Source: National Renewable Energy Lab 2007

Low Wind Speed Case Studies: Puerto Rico Wind Farm Projects

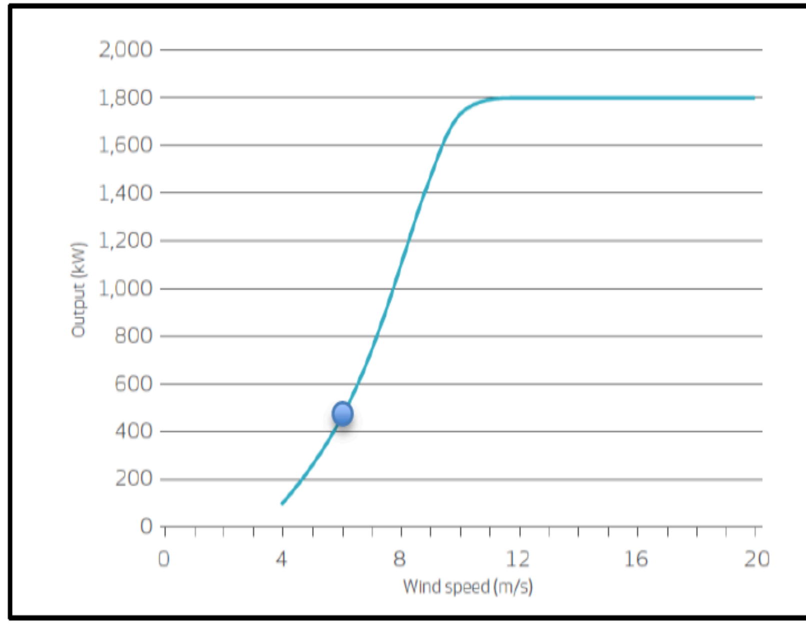
Finca de Viento Santa Isabel (Santa Isabel) Wind Farm

- Developer, Pattern Energy, performed studies before the wind farm was constructed
- Reported to have an average wind speed of **6.5 m/s (14.5 mph)**

Punta de Lima Wind Farm

- According to developer, Gestamp Wind, "this wind farm will generate 52 GWh per year…"
- Each turbine is 1.8 megawatts
- Capacity factor of approximately 25%
- Average hourly output is 450 kilowatts (25% of 1.8 megawatts)

Figure 2. Vestas V100-1.8 Power Curve



Source: Vestas V100-1.8 Brochure

Based on the turbine power curve above, the site may achieve an average of 6 m/s (13.4 mph) wind speeds

Low Wind Speed Case Studies: Puerto Rico Wind Farm Projects

- Average annual wind speeds for the two wind farms are approximately **6-6.5** meters per second (m/s)
- NREL map inaccurate suggests undevelopable (anywhere from 0-5.9 m/2)
- Outdated hub heights (50 meters)
- New NREL report on U.S Virgin Islands report: recognized St. Thomas, St. Johns, and the Bovoni peninsula as *"prime candidate[s] for utility-scale wind generation."* Some areas may contain average wind speeds of 7.0-7.5 m/s

Low Wind Speed Case Studies: University of Delaware Wind Turbine

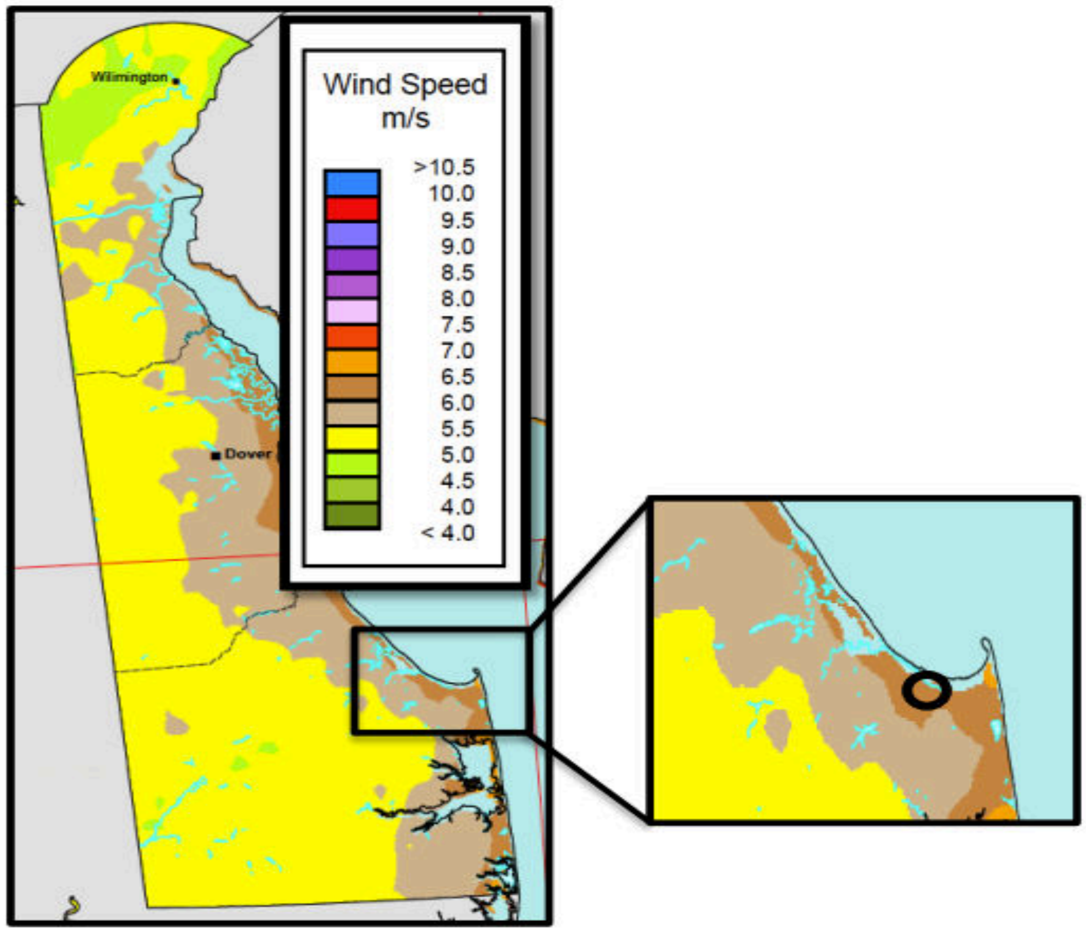
- University of Delaware (UD) installed a turbine on the Campus in Lewes, Delaware
- 2 MW turbine
- Installed in 2010
- Turbine has been a success, powering the Lewes campus with a surplus of 1.3 million kilowatt-hours


Credit: Evan Krape, UDaily News

Low Wind Speed Case Studies: University of Delaware Wind Turbine

- NREL, 2010: Approximately 6.0 m/s (13.4 mph)

Figure 2. Delaware Average Annual Wind Speeds (80 Meters)



Low Wind Speed Case Studies: University of Delaware Wind Turbine

- In May 2009 UD conducted feasibility report for wind turbine development
- UD predicted average wind speeds at a height of 80 meters
- In this report, UD predicted average wind speeds at a height of 80 meters were approximately **6.74 m/s (15 mph)**.

Figure 1. University of Delaware Wind Resource Assessment and Output Modeling

Potential Turbine Location	Mean Wind Speed at Hub Height	Annual Energy Output
Location 1	6.74 m/s	4,023,375 kWh

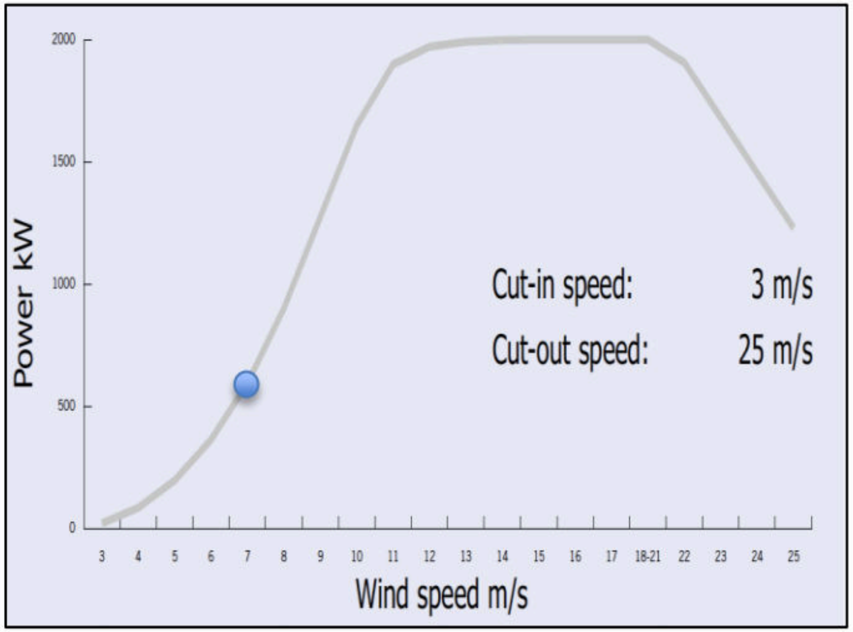
Source: UD Technical Analysis for On-Site Wind Generation 2009

*[*Note: While 5 locations were analyzed, Location 1 was the closest to the current site of the UD turbine.]*

Low Wind Speed Case Studies: University of Delaware Wind Turbine

- Data from the actual wind farm production can help us to more accurately determine the average wind speed:
- From June 2010-May 2011: UD wind turbine produced 5,100 megawatt-hours of electricity (even better than estimated in the report: 4,023 megawatt-hours)
- The turbine is 2 MW
- Capacity factor of approximately 29%
- Average hourly output is 580 kilowatts (29% of 2 megawatts)

Figure 3. Gamesa G90-2.0 MW Power Curve



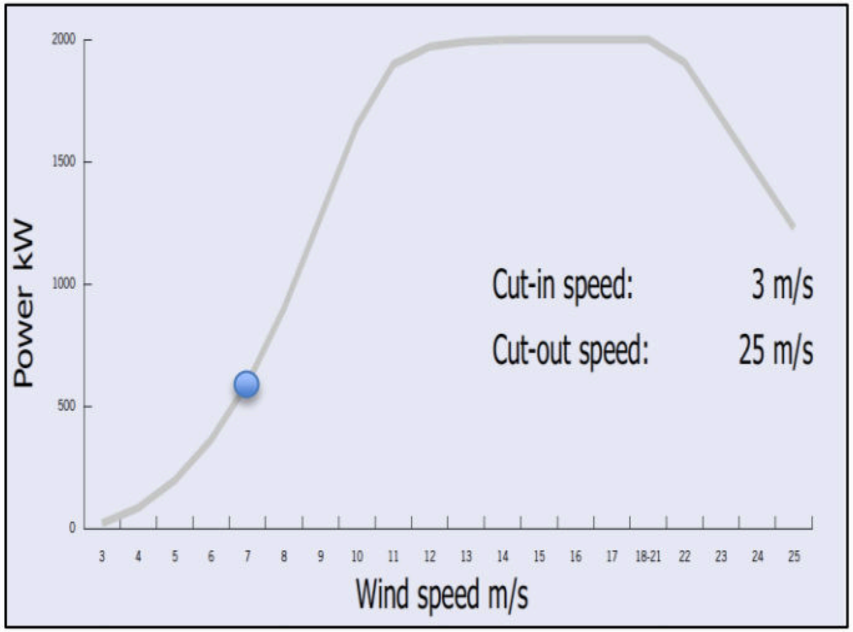
Source: Gamesa G90-2.0 MW Brochure

Based on the turbine power curve above, the site may achieve an average of 7 m/s wind speeds

Low Wind Speed Case Studies: University of Delaware Wind Turbine

- NREL: 6.0 m/s would place the wind project way below a 500 kilowatt per hour output
- Capacity factor of only 15-20%
- Actual output at the UD Lowes turbine approximately double than what would be expected using the NREL map with the estimated wind speed.

Figure 3. Gamesa G90-2.0 MW Power Curve



Source: Gamesa G90-2.0 MW Brochure

Low Wind Speed Case Studies: Arkansas Wind Energy Resource

- AWS Truepower, LLC performed year-long extensive study in 2011 on Arkansas' wind resource
- 5 communication towers 90-120 meters selected for wind monitoring
- Estimated long-term mean wind speeds were determined from various heights

"The long-term projected speeds at height of 80 m[eters] and above suggest that commercial wind development in these areas of the State is feasible, in part due to technological advancements in the industry."

Credit: AWS Truepower, LLC

Low Wind Speed Case Studies: Arkansas Wind Energy Resource

Table 6. Extrapolation of Climate-Adjusted Speeds to Different Heights

Tower Number	Monitoring Height (m)	Climate-Adjusted Speed (m/s)	Effective Wind Shear	Projected 80-m Speed (m/s)	Projected 100-m Speed (m/s)	Projected 120-m Speed (m/s)	Projected 150-m Speed (m/s)
ARK1	76.3	6.31	0.274	6.46	6.87	7.22	7.68
ARK2	70.8	5.67	0.416⁺/0.374⁺⁺	5.97	6.55	7.01	7.62
ARK3	96.1	5.76	0.396*/0.357**	5.36	5.84	6.24	6.75
ARK4	96.4	6.05	0.437*/0.393**	5.58	6.14	6.60	7.20
ARK5	86.3	5.39	0.356	5.25	5.68	6.06	6.56

⁺Shear applied for 80 m and 100 m hub height wind speed estimates

⁺⁺Shear reduced by 10% and used to estimate wind speeds at the 120 m and 150 m heights

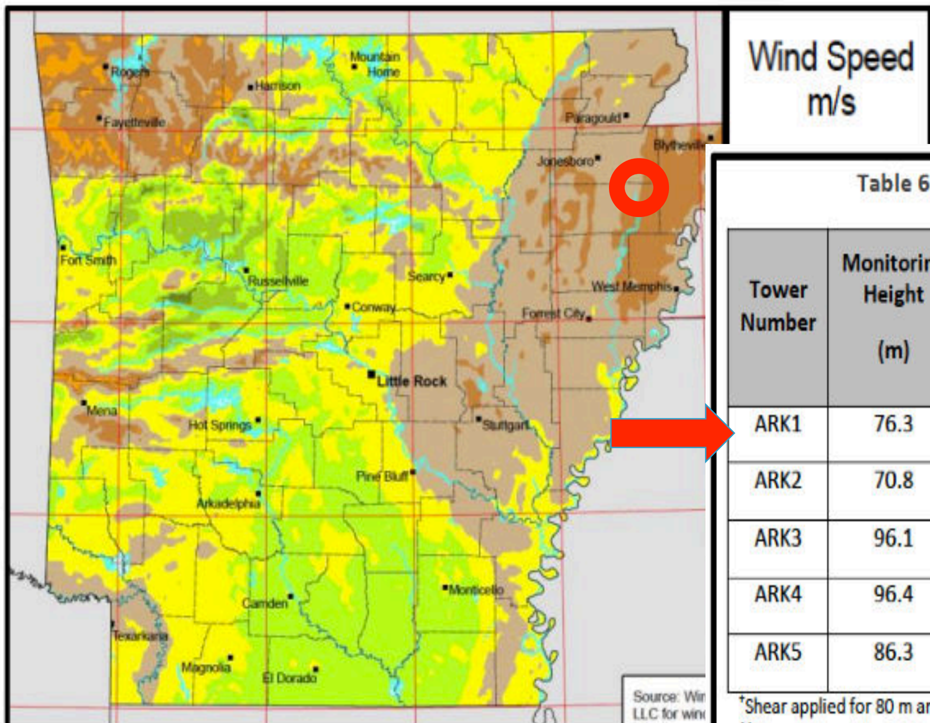
*Shear applied for 80 m hub height wind speed estimate.

**Shear reduced by 10% and used to estimate wind speeds at heights above top monitoring level.

Credit: AWS Truepower, LLC

Low Wind Speed Case Studies: Arkansas Wind Energy Resource

Figure 1. Arkansas Average Annual Wind Speeds (80 Meters)



Source: National Renewable Energy Lab 2010

NREL 80 meter map:
- **6.0-6.5** m/s (13.4-14.5 mph)

Table 6. Extrapolation of Climate-Adjusted Speeds to Different Heights

Tower Number	Monitoring Height (m)	Climate-Adjusted Speed (m/s)	Effective Wind Shear	Projected 80-m Speed (m/s)	Projected 100-m Speed (m/s)	Projected 120-m Speed (m/s)	Projected 150-m Speed (m/s)
ARK1	76.3	6.31	0.274	6.46	6.87	7.22	7.68
ARK2	70.8	5.67	0.416†/0.374††	5.97	6.55	7.01	7.62
ARK3	96.1	5.76	0.396*/0.357**	5.36	5.84	6.24	6.75
ARK4	96.4	6.05	0.437*/0.393**	5.58	6.14	6.60	7.20
ARK5	86.3	5.39	0.356	5.25	5.68	6.06	6.56

†Shear applied for 80 m and 100 m hub height wind speed estimates
††Shear reduced by 10% and used to estimate wind speeds at the 120 m and 150 m heights
*Shear applied for 80 m hub height wind speed estimate.
**Shear reduced by 10% and used to estimate wind speeds at heights above top monitoring level.

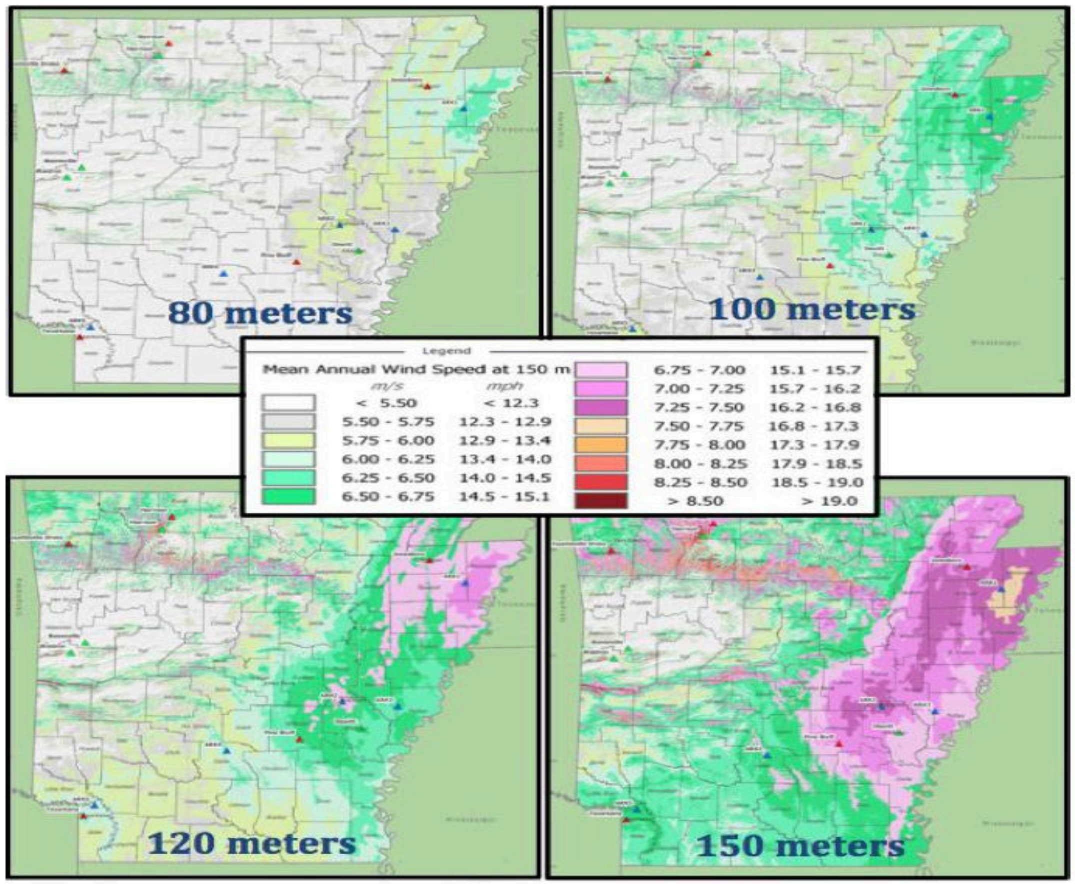
Credit: AWS Truepower, LLC

Low Wind Speed Case Studies: Arkansas Wind Energy Resource

Increasing the hub height of the wind turbine:

- Increases capacity factors
- Increasing annual output
- Decreases cost

Figure 2. Arkansas Average Annual Wind Speeds at Multiple Heights (80 m, 100 m, 120 m, and 150 m)



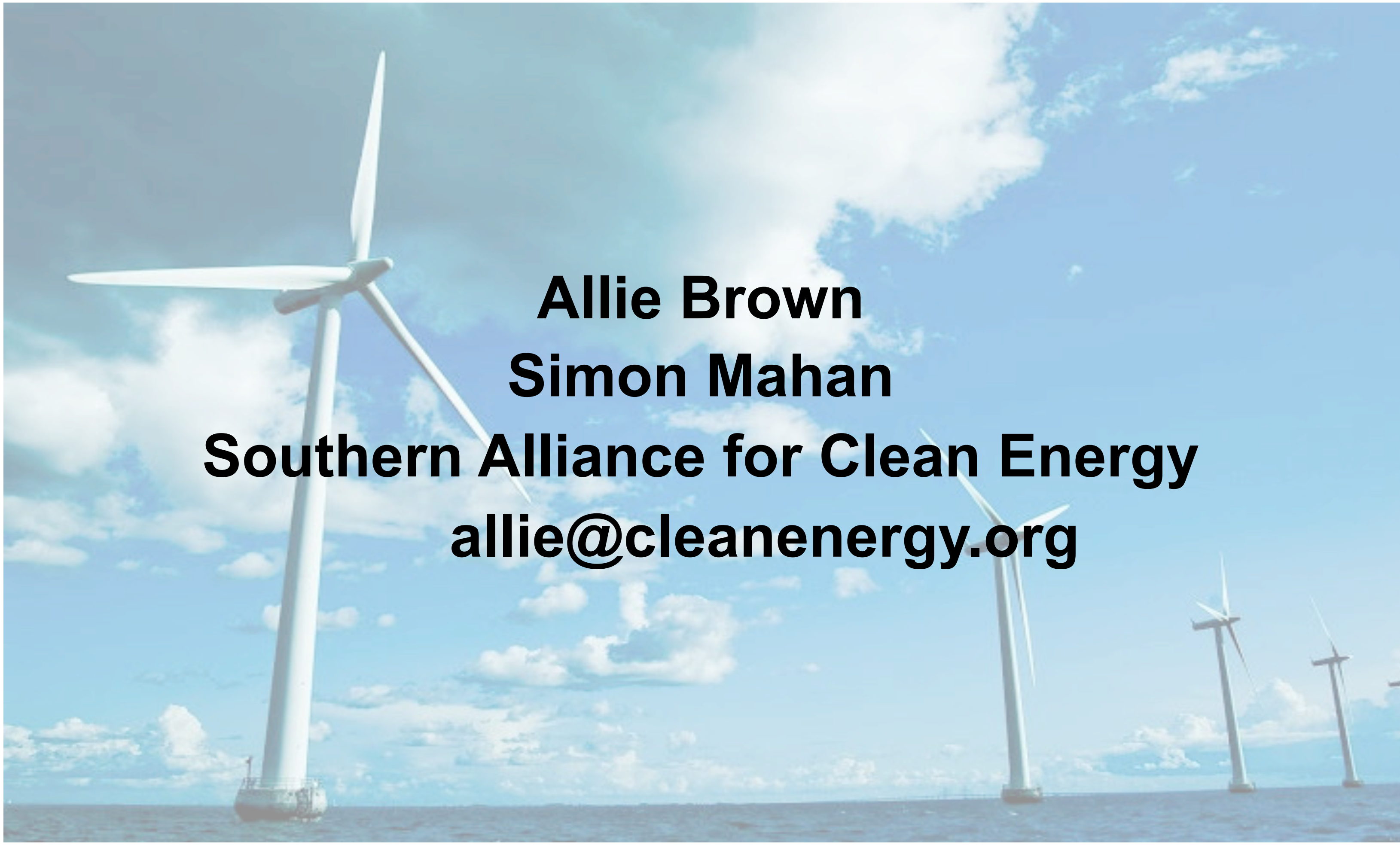
Source: AWS Truepower 2012

Conclusions

Takeaway:

- Advanced turbine technology has allowed for greater capacity factors and lower costs
- NREL suggest there are 134,000 megawatts available throughout the Southeast
- With this new turbine technology, there is a need for wind resource assessment maps to reflect these elevated opportunities
- Wind speed maps alone cannot predetermine the viability of a wind farm
- Two key issues with maps:
  - Too coarse to identify ridge resources
  - Outdated with only 80 meter hub heights or lower
- Case studies show that 1 m/s difference in average wind speed makes a significant difference in electricity produced in a year
- Majority of case studies showed that turbines produced double what would be expected from the maps

Thank you!



Allie Brown
Simon Mahan
Southern Alliance for Clean Energy
allie@cleanenergy.org