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Learning from the Experts

This webinar series is hosted by NYSERDA’s offshore wind team and features experts in offshore wind technologies, development practices, and related research.

DISCLAIMER: The views and opinions expressed in this presentation are those of the presenter and do not represent the views or opinions of NYSERDA or New York State.
Offshore Wind Technology 101

Walt Musial
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Today’s Topics

- Wind history and how wind turbines work
- Offshore wind resources
- What’s above the water?
- What’s under the water?
- Why offshore wind?
- Floating wind
- How much does offshore wind cost?
- What are the conflicts and environmental challenges?
How does a wind turbine work?

- The **rotor** captures wind that creates torque (rotational force) that spins a low-speed shaft.
- The **gearbox** increases the shaft speed which turns a generator.
- Many offshore turbines now have **direct drive generators**.
- The generator produces **electricity**.
- Multiple turbines are connected to form a **wind farm**.
- Offshore wind farms generate as much energy as coal, natural gas, or nuclear power plants.
History of Wind Technology

What did we learn in the 1980’s?

Over 10,000 Machines installed at Altamont, Tehachapi, and San Gorgonio Passes in California between 1981 and 1985

“Survival of the Fittest”
Vertical Axis or Horizontal Axis?
Downwind or Upwind Rotors?
How Many Blades?

1. 
2. 
3. 
4. 
5. 
6.
Lattice or Tube Towers?
Small or Large Turbines?

Wind Wall in Tehachapi CA -1985

V-90 Turbine – Same Output-3MW
Modern Wind Turbine Architecture

- Horizontal Axis
- Upwind
- Three Blades
- Tube Towers
- Large Scale
The 30-MW Block Island Wind Farm is the first offshore wind plant in the United States

- Five 6-MW GE Haliade turbines installed in 2016 east of Block Island Rhode Island
- The provides enough power for up to 16,000 Rhode Island homes – many times more than Block Island uses
- A submarine cable was installed to deliver the excess power to the mainland
How Much *Power* Does a Wind Turbine Produce?

\[ \text{Power in the wind} = \frac{1}{2} \rho A V^3 \]

\(\rho = \text{density of air} = 1.23 \text{ kg/m}^3\) at sea level

\(A = \pi r^2 = \text{area of the circle swept by the blades (m}^2\text{)}\)

\(V = \text{wind speed flowing toward the blades (m/s)}\)

- Power in the wind increases as the *SQUARE* of the blade length.
  
  If the radius is *doubled*, the power is *quadrupled*.

- Power in the wind increases with the *CUBE* of the incoming wind!
  
  If the wind speed *doubles* the power in the wind increases *eight times*!

Siemens 2.3 MW floating offshore wind turbine, North Sea, Norway. Photo credit: Senu Sirnivas (NREL).
The wind turbine is idle until cut-in wind speed is reached (typically 4 m/s [9 mph]).

For winds greater than cut-in, the power increases with the cube of the windspeed – about half the power in the wind is converted to electricity.

When the power reaches the generator rating ("rated power") the wind turbine blades pitch to maintain rated power.

At the cut-out wind speed the wind turbine is shut down to save wear and tear. Winds above cut-out are very rare.

These operations are automated, but humans can override these controls in an emergency.

One GE Haliade-X offshore wind turbine is rated at 12 megawatts and can provide enough power for about 6,500 New York residences.
Where Are the Best Offshore Wind Resources?

- Wind resource maps show best offshore wind sites.
- U.S. offshore wind potential is 2 times larger than the electricity we use.
- Best sites have high steady winds and shallow waters.
- Data Filters

Areas shown on map have water depth less than 1,000 meters (3,280 feet)

AND

Average annual wind speeds greater than 7 meters/second (15.7 miles per hour)
Wind Speeds at Hub Height are Difficult to Get

- Wind speed increases with height – “wind shear”
- Taller towers mean more incoming wind to spin the turbine and more energy
- It's important to know the wind at hub height but buoys and fixed stations are too close to surface
- Wind measurements are now made using LIDAR systems

Wind speed increases with elevation due to wind shear
How Do We Determine The Wind Resource?

High Fidelity Computer Models
• Global weather models are used to estimate wind speed over various geographic areas and time intervals
• Models calculate data every 5 minutes and every location on 2-kilometer by 2-kilometer squares

Validation Measurements
• Measurements are used to validate and improve the accuracy of the models
• Measurements at sea are very difficult and expensive

*LIDAR stands for Light Detection and Ranging and is the state-of-the-art technology for ocean-based measurements at elevations where wind turbines operate
At a given site:

- Wind speed varies by the hour of the day, seasonally, and inter-annually
- Annual wind speeds are plotted in histograms (bottom left) and are approximated by Weibull distribution
- Wind direction also varies and is plotted in a “wind rose” (upper left)
- Other important variables include turbulence intensity, atmospheric stability, and wind shear
- All of these characteristics affect energy production – wind speed is the most important.
How Large Will Offshore Turbines Get?

- Offshore turbines are more than twice as big as land-based.
- Fewer installation and transportation constraints offshore.
- Larger turbines lower project costs.
- No hard limits to further turbine growth.
- Infrastructure constraints may ultimately limit growth.

Expected Turbine Growth – 15 MW by 2030
Technology Innovations Enable Larger Turbines

- Advanced light-weight materials
- Advanced controls to limit loads and protect vital systems
- High-fidelity design and analysis tools
- Material and manufacturing innovations
- Automated service and logistics
- Remote diagnostics and robotic repairs
- Industrialization of the supply chain
Offshore Wind Turbine Size Comparison

Source: GE Vox Research
Turbine Spacing Increases With the Rotor Diameter

Illustration Shows How Turbine Spacing is Determined Within and Array

For a GE 12-MW Haliade-X with 8D spacing, the turbines would be over 1 mile apart
What’s Below the Water?
Balance of Station – Non-turbine Capital Equipment

- Inter-array cables
- Offshore support structures
- Export cable – main cable to shore
- Onshore substation

- Installation and assembly costs
- Engineering and Design
- Insurance
- Soft costs

75% of the Cost of an Offshore Wind Plant
Offshore Wind Support Structures are Water Depth Dependent

For water depths 0 to 60 m fixed bottom support structures are expected to be most economical.

For water depths greater than 60 m, floating support structures are expected to be most economical.
Monopiles represent over 70% of installed offshore turbines globally. Deeper water and difficult soil conditions are driving other substructure types. For depths greater than 60 m, industry is developing floating support structures.
Offshore Wind Turbines with Monopiles

Baltic 1 Wind Plant
Photo credit: Walt Musial

Bremerhaven Port Staging
Photo credits: Gary Norton
Jackets and Tripods at Alpha Ventus - Germany

Photo Credit: Gary Norton
Fixed-Bottom Installation


Utility scale offshore wind farms collect the power from each turbine at a high voltage substation for transmission to shore.

Floating substations are being developed with dynamic cables that allow the substations to move with the waves.
In-situ Repairs Fixed and Floating: Done in the field using service vessels - Sensors/computers, lubrication, electrical, preventative maintenance

Major Floating Wind Repairs – Blades, Generators, Gearboxes – Can be done by disconnecting mooring lines and towing system to port
Serial turbine, substructure assembly and component port delivery due to depth, waves off coast.

Storage and wet-tow out of assembled turbines with year-round access. Width/depth varies by substructure design.

100’s acre storage and staging of blades, nacelles, towers, possible fabrication of floating substructures.

High lift capacity at 500 feet height to attach components.

Moorage for crew access vessels. O&M berth for major repairs of full system.
Why Pursue Offshore Wind Energy?

- Generation close to load (80% of the population lives on the coast)
- Stronger winds
- Larger scale projects are possible
- Unique economic benefits
- Revitalizes ports and domestic manufacturing
- Less constrained by transport and construction

Offshore resource shown only from 0 to 50 nautical miles from the coast. US waters extend to 200 nm from coast.
At the end of 2019, the UK had the most installed offshore wind, with 8,478 MW.

UK growth has been relatively steady for the past decade.

Germany installed 7,441 MW of offshore wind by the end of 2019.

German market accelerated in 2015 with steady growth since.

China’s cumulative capacity is third in the world, with a total of 6,000 MW installed, and is growing the fastest.
Where in the U.S. is Floating Offshore Wind Being Considered?

58% of the U.S. offshore wind resource is in water depths > 60m - floating foundations

- **Pacific Region** – High water depths require floating technology
- **North Atlantic** – high demand, scarcity of shallow sites
- **Great Lakes** – visual impacts may require farther distances

Figure credit: NREL
Oil and Gas Experience Helped Accelerate First Generation

• Basic archetypes are derived from oil and gas experience
• Oil & gas criteria result in successful, but bulky and expensive designs
• Next phase: Optimized engineering approach will yield commercial systems
First Commercial Floating Wind Farm

30-MW Hywind-2 (2017)

• First floating wind farm off Peterhead, Scotland
• Five 6-MW Siemens turbines were installed by Equinor in 2017
• Substructure type: Spar Buoy
• Water depth: up to 130 m (427’)
• Hub height: 101 m (331’)
• Rotor diameter: 154 m (505’)

Siemens 6-MW Wind Turbine at Hywind -2

Photo credit: Walt Musial
WindFloat Atlantic Floating Wind Farm

25-MW WindFloat Atlantic (2019)

- Near Porto, Portugal in 2019
- Windplus consortium includes EDP Renewables, ENGIE, Repsol, and Principle Power.
- Three 8.4-MW Vestas turbines
- First power December 31, 2019
- Water depth: 100 m (328’)
- Hub height: 100 m (328’)
- Max height above water: 190 m (623’)

Source: Windplus/Dock90
Prices from Recent European Offshore Wind Auctions Indicate Some Fixed-bottom Projects Can Compete Without Subsidies

Why are offshore wind prices falling?
- Technology improvements (e.g. Larger Turbines)
- Lower risk
- Maturing supply chains
- Increased competition

U.S. power purchase agreement analysis indicates same cost reduction trends
Floating Wind Energy Costs Follow Fixed-bottom Offshore Wind Trends

- Shared supply chains
  - Turbines
  - Array and export cables
  - Regulations
  - Ports and Infrastructure
  - Operations and Maintenance
- Floating cost reductions lag fixed-bottom offshore wind cost by 5-7 years
- Floating cost are likely to converge with fixed-bottom wind

Figure credit: NREL
• **4C Offshore** predicts that cumulative U.S. offshore wind deployment will exceed 25,000 MW by 2030 (4C Offshore 2019).

• **BNEF** predicts cumulative U.S. offshore wind deployment will grow to nearly 19,000 MW by 2030 (BNEF 2019).

• These estimates are 50% to 70% higher than in their 2018 estimates when BNEF and 4C Offshore predicted 11,000 MW and 16,000 MW, respectively, by 2030.

• New accelerated offshore wind deployment targets for United States – 30GW by 2030
Thank you for your attention!

Questions?

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Photo Credit: Dennis Schroeder-NREL
Coming Next:

April 28, 1:00 p.m. ET
Article VII Permitting Process for Offshore Wind
Bill Flynn, Harris Beach PLLC
Visit wind.ny.gov to register

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