Learning from the Experts Webinar Series

Offshore Wind Technology 101

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April 7, 2021

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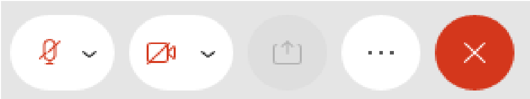

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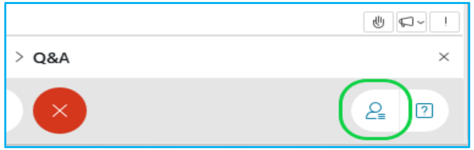

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Learning from the Experts

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

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Offshore Wind Technology 101

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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?

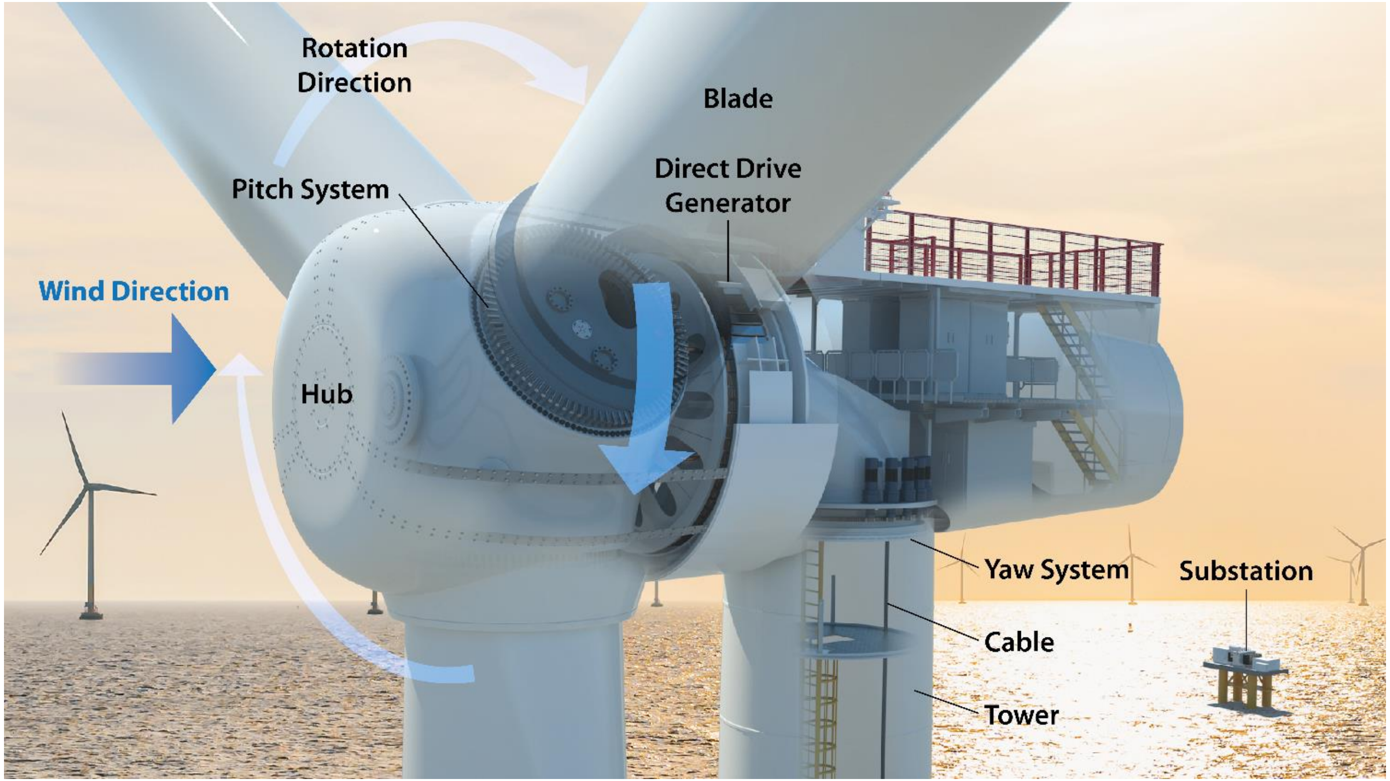


Figure credit: Joshua Bauer, NREL

- 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?



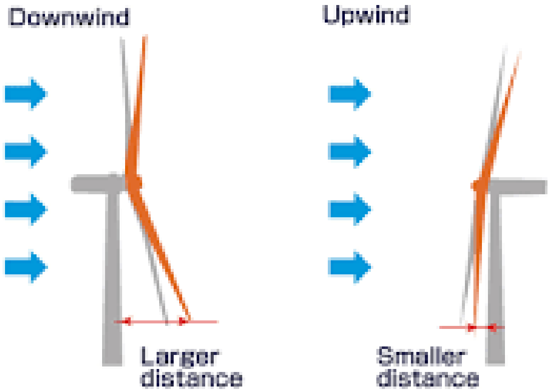
Over 10,000 Machines installed at Altamont, Tehachapi, and San Gorgonio Passes in California between 1981 and 1985

"Survival of the Fittest"

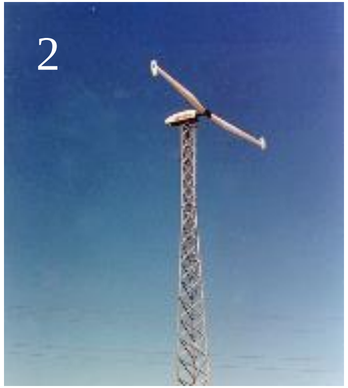
Why do Wind Turbines Look Like This?

Vertical Axis or Horizontal Axis?

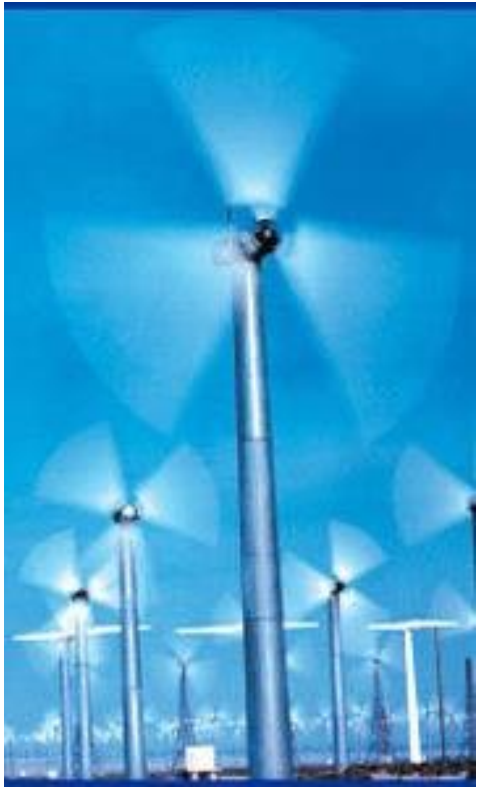
Downwind or Upwind Rotors?



How Many Blades?



Lattice or Tube Towers?



Small or Large Turbines?

Wind Wall in Tehachapi CA -1985

V-90 Turbine – Same Output-3MW

Block Island Wind Farm

Oct 1, 2016

<u>Modern Wind Turbine Architecture</u>

- 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?

$$\textbf{Power in the wind} = \frac{1}{2}\rho\, A\, V^3$$

ρ = density of air = $1.23\ \frac{\text{kg}}{\text{m}^3}$ at sea level

$A = \pi\, r^2$ = area of the circle swept by the blades (m^2)

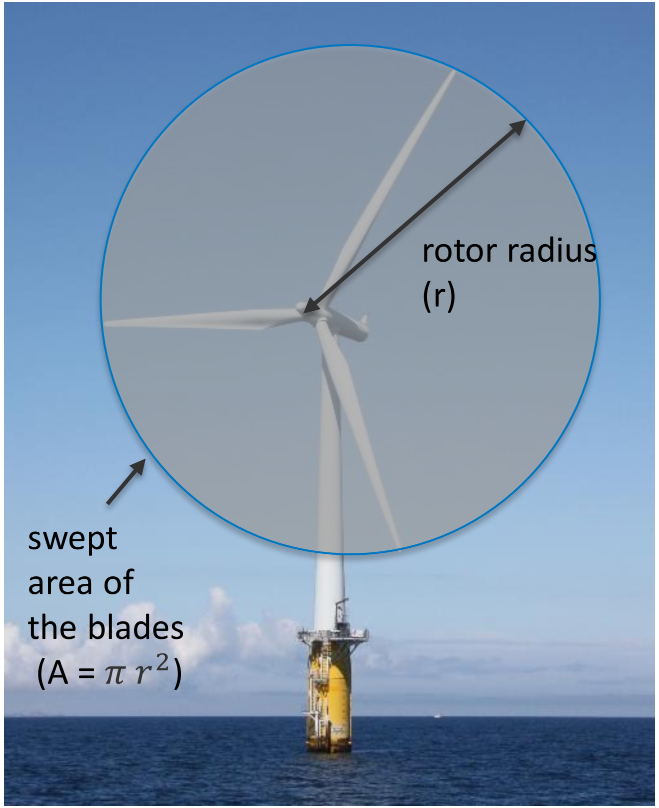
V = wind speed flowing toward the blades $\left(\frac{m}{s}\right)$

- **Power in the wind increases as the SQUARE of the blade length.**

If the radius is <u>doubled</u>, the power is <u>quadrupled</u>.

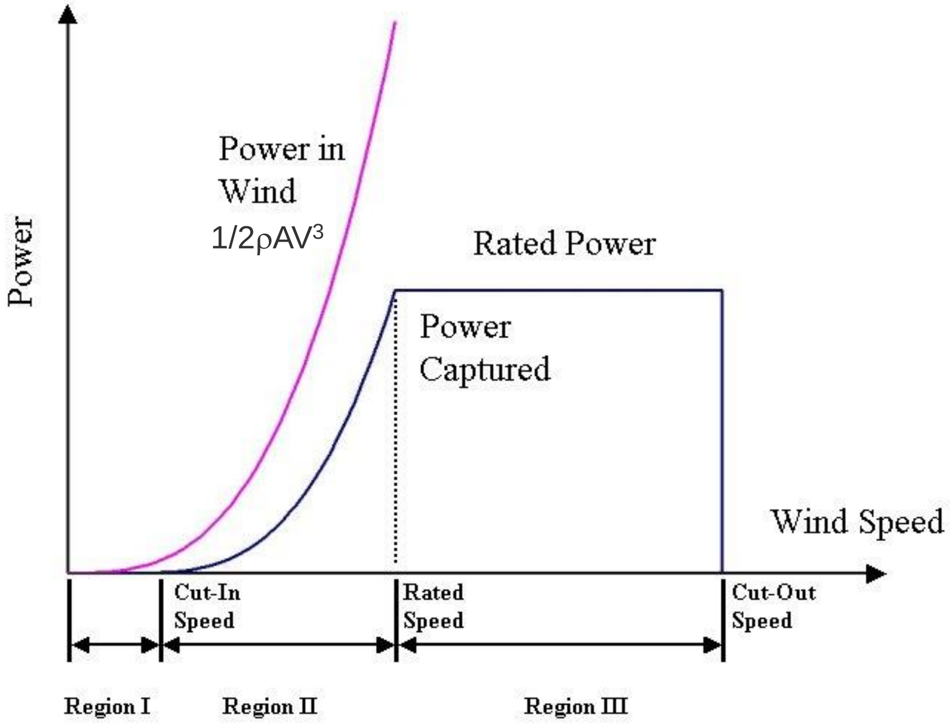
- **Power in the wind increases with the CUBE of the incoming wind!**

If the wind speed <u>doubles</u> the power in the wind increases <u>eight times</u>!



Siemens 2.3 MW floating offshore wind turbine, North Sea, Norway. Photo credit: Senu Sirnivas (NREL).

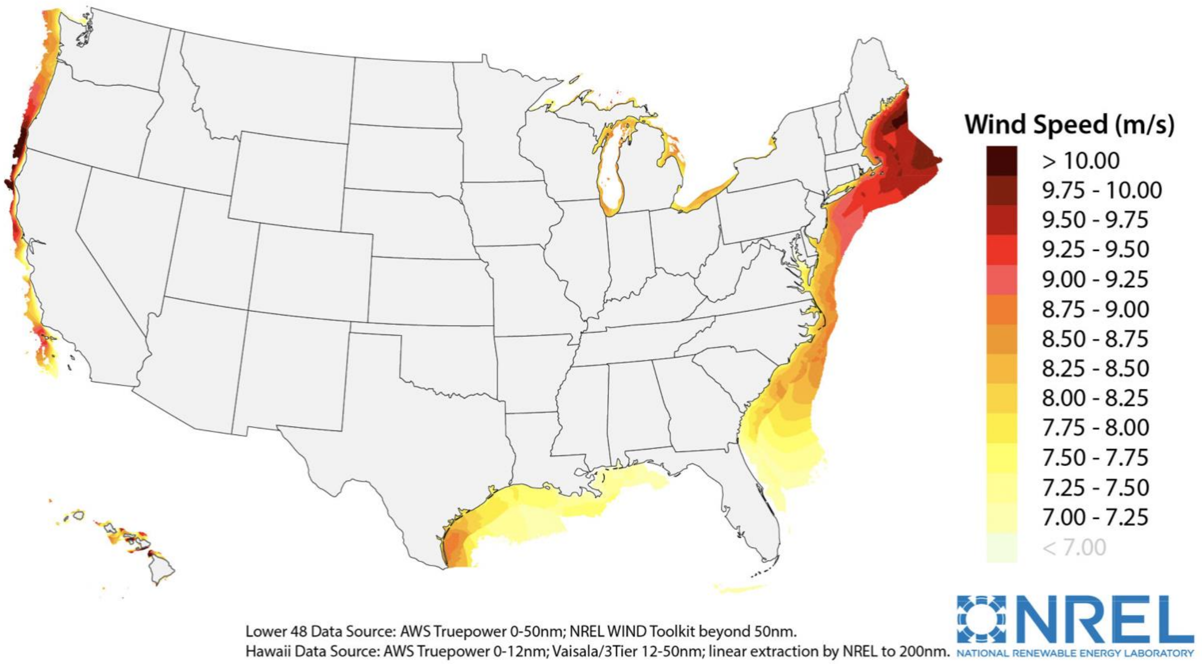
Typical Wind Turbine Power Curve



- 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?



U.S. Offshore Wind Technical Resource Area

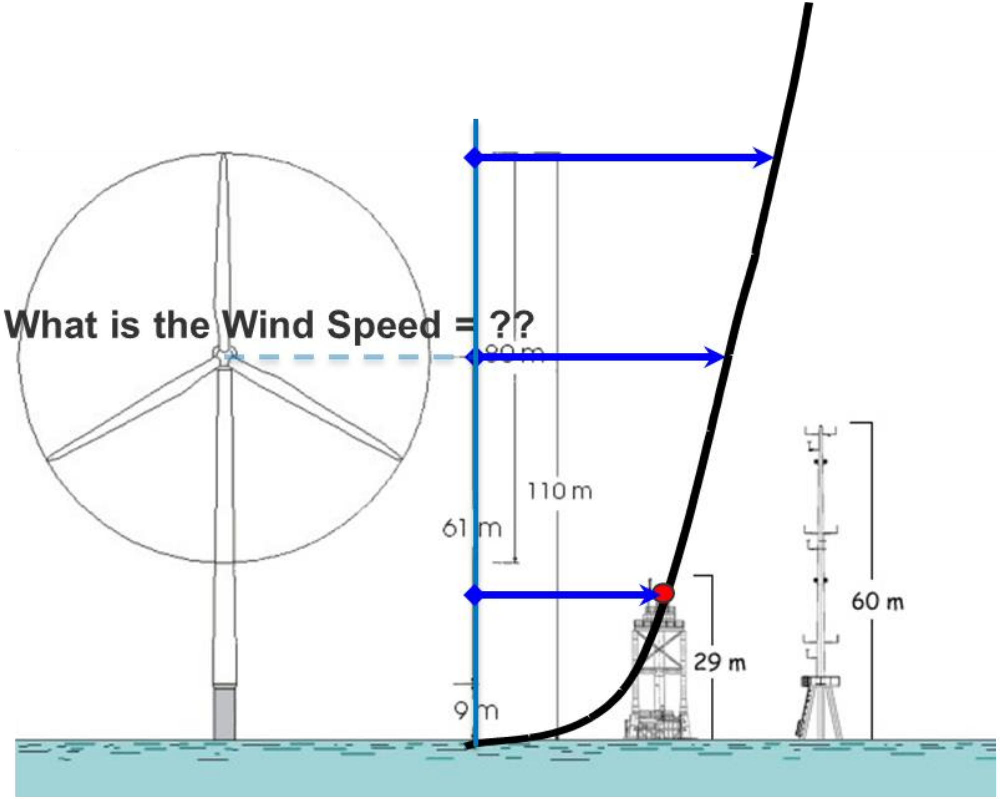
- Wind resource maps show best offshore wind sites
- U.S. offshore wind potential is 2 times larger than the electricity we use
- Best sites have high steady winds and shallow waters
- Data Filters

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 elevation due to wind shear

- Wind speed increases with height – “wind shear”
- Taller towers means 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

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

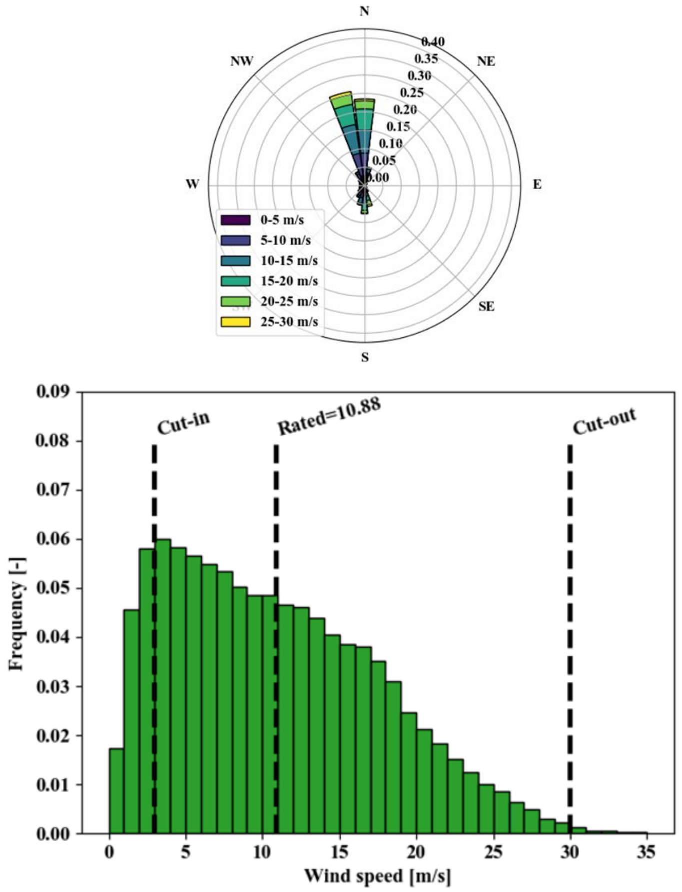
Validation Measurements

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

Offshore wind measurements come from ocean buoys, floating LIDAR* (left) or from meteorological towers (right).

*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

Wind Resource Statistics

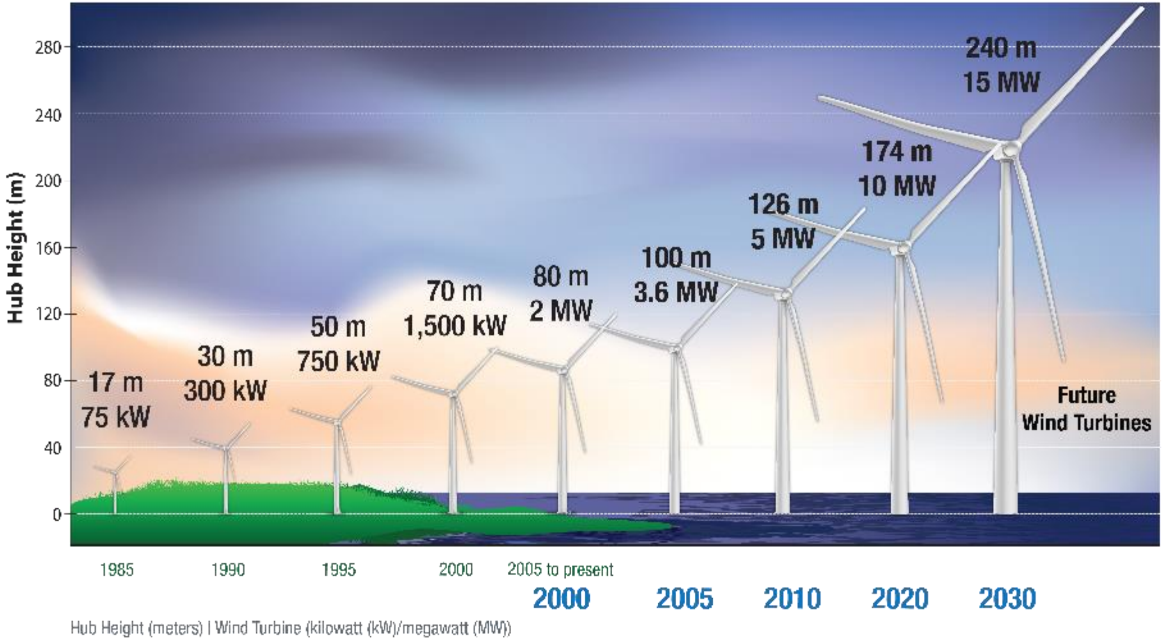


Wind Rose and Probability Distribution for Humboldt Call Area

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?



Expected Turbine Growth – 15 MW by 2030

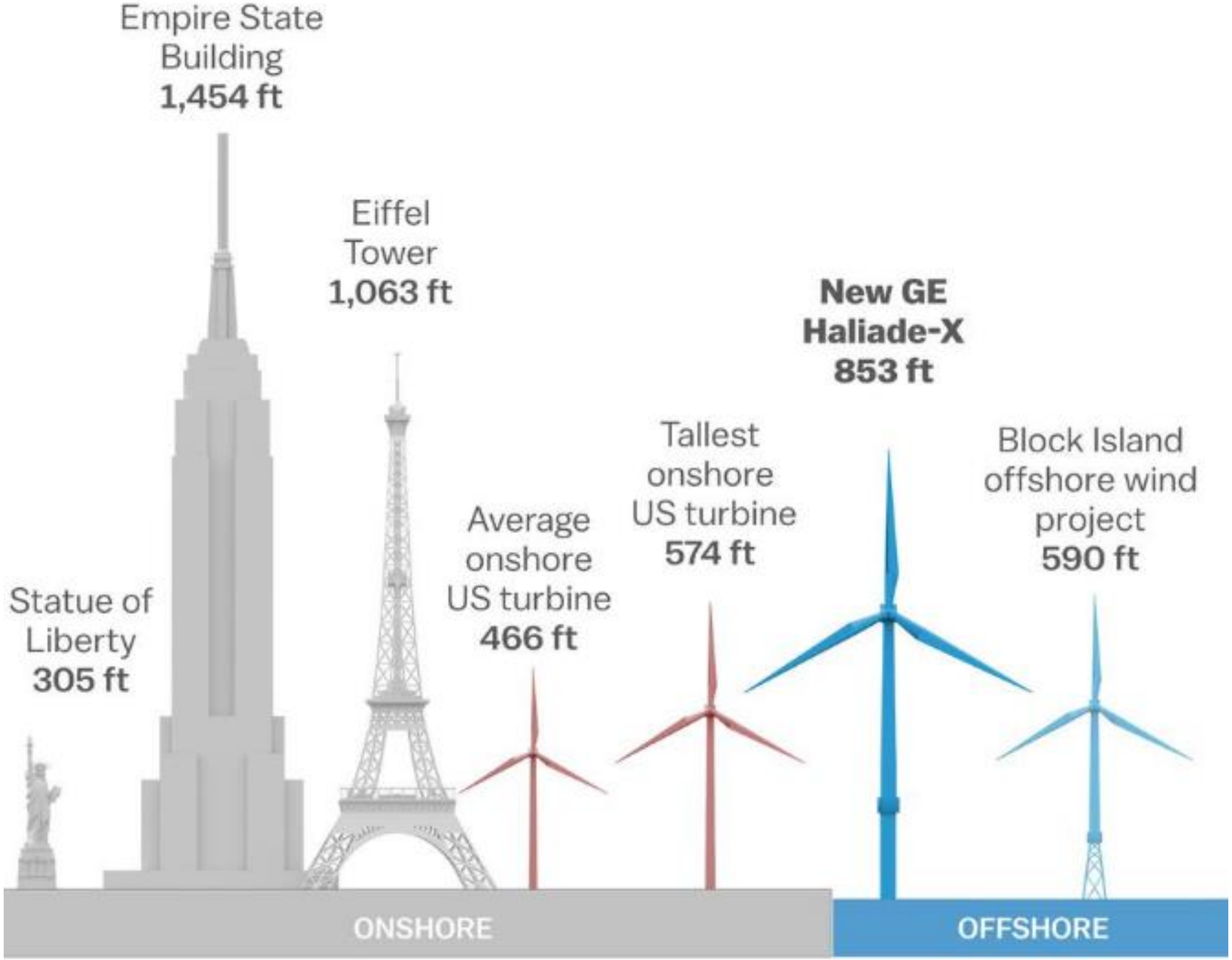
- Offshore turbines are more than twice as big as land-based
- Fewer installation and transportation constraints offshore
- Larger turbines lower project costs
- No hard limits to further turbine growth
- Infrastructure constraints may ultimately limit growth

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

GE 12-MW Wind Turbine Nacelle (above) and 107-m Blade Below)

Offshore Wind Turbine Size Comparison



Source: GE Vox Research https://www.vox.com/energy-and-environment/2018/3/8/17084158/wind-turbine-power-energy-blades

Turbine Spacing Increases With the Rotor Diameter

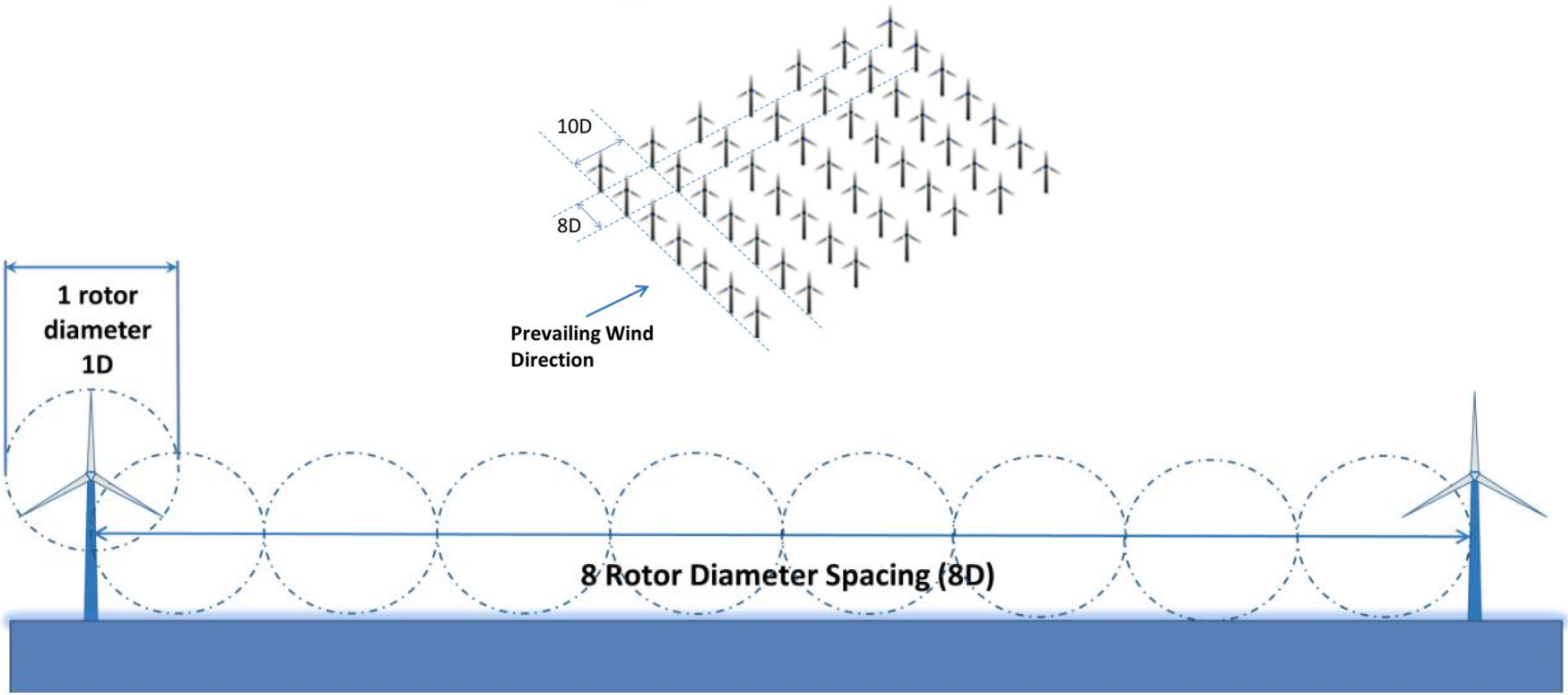
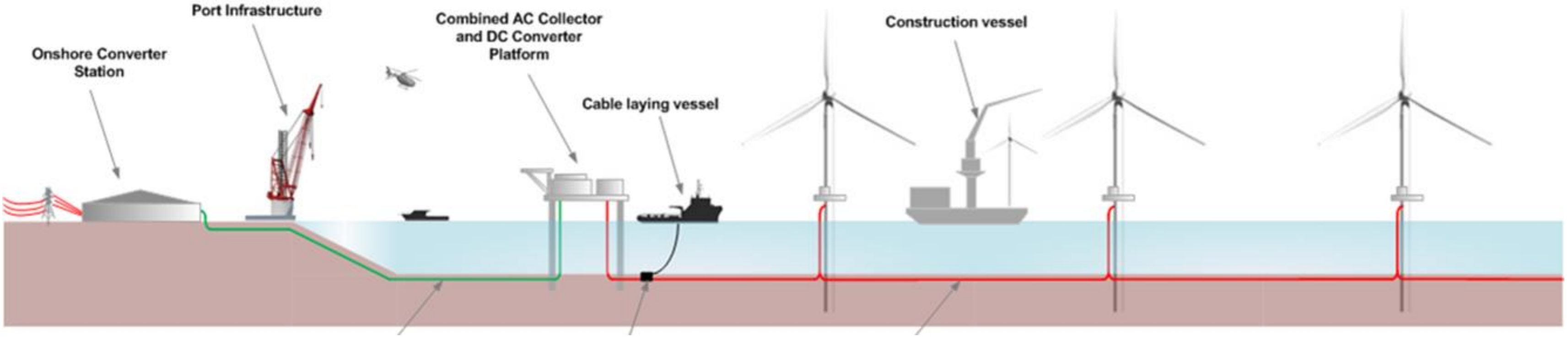


Illustration Shows How Turbine Spacing is Determined Within and Array

For a GE 12-MW Haliade-X with 8D spacing, the turbines would be over 1 mile apart

What’s Below the Water?

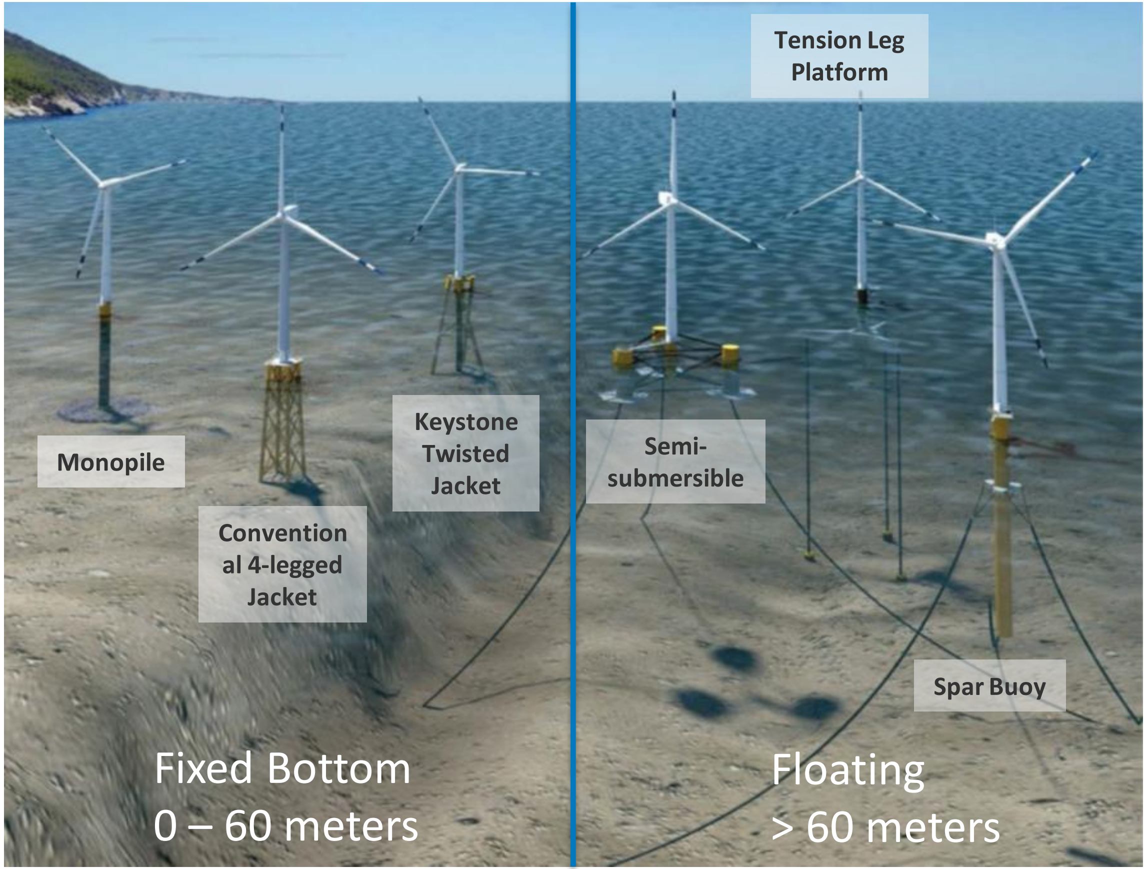
Balance of Station – Non-turbine Capital Equipment



- 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

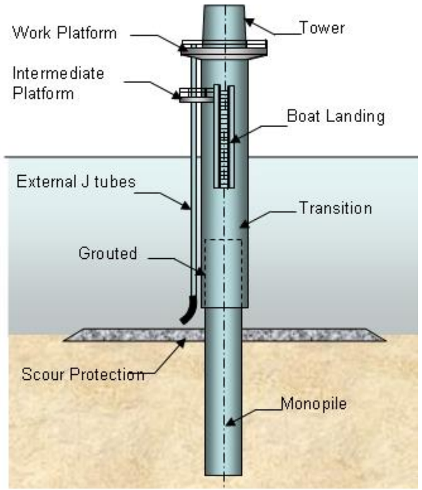
Offshore Wind Support Structures are Water Depth Dependent



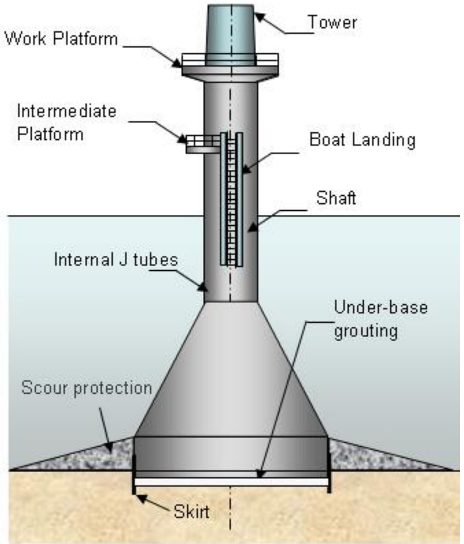
For water depths 0 to 60 m fixed bottom support structures are expected

For water depths greater than 60 m, floating support structures are expected to be most economical

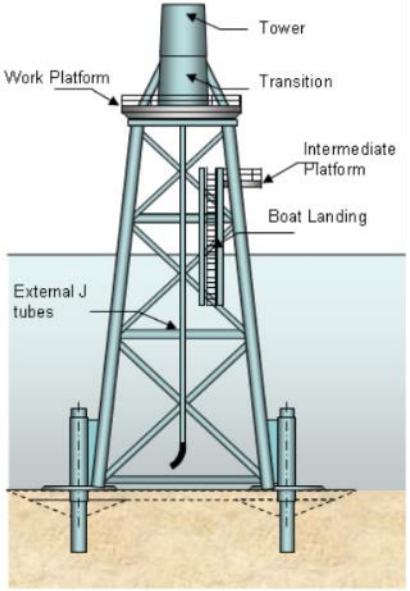
Fixed Bottom Turbine: Common Substructure Types



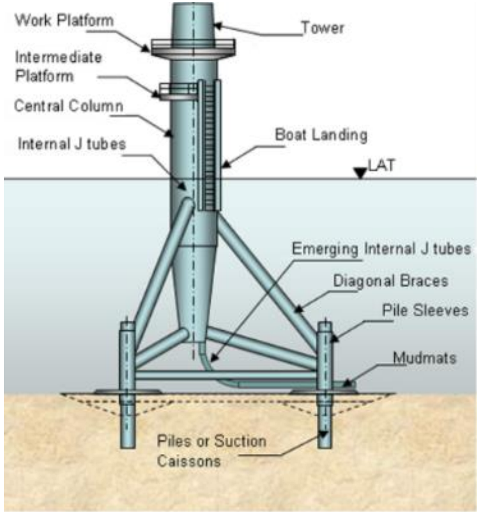
Monopile



Gravity Base



Jacket



Tripod

- 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

Fixed-Bottom Installation

Jack-up barge. London Array Offshore Wind Farm, Thames Estuary, United Kingdom. Photo credit: Siemens Press Picture. 2012.

Jack-up barge. Borkum Riffgat Offshore Wind Farm, North Sea, Germany. Photo credit: Siemens Press Picture. 2013.

Baltic 1 - Substation

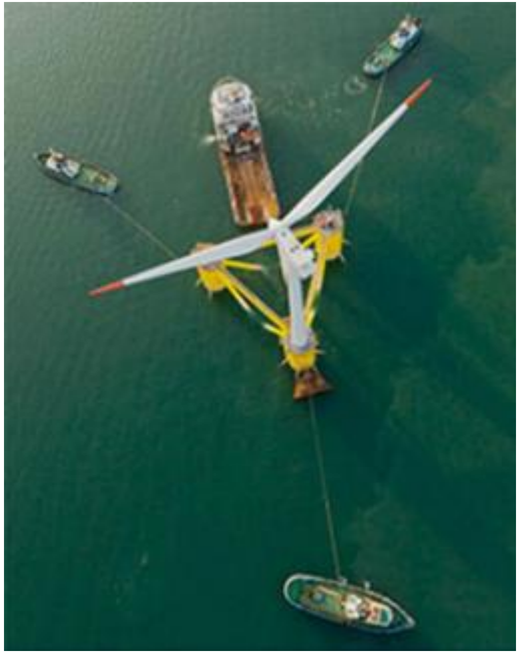
- Utility scale offshore wind farms collect the power from each turbine at a high voltage substation for transmission to shore

- Floating substations are being developed with dynamic cables that allow the substations to move with the waves.

Operations and Maintenance

Turbine Service Vessel Baltic 1

Photo: Walt Musial



Floating Turbine Tow-out

Photo: Principle Power

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

Offshore Wind Port and Infrastructure Requirements

Image by Harland and Wolff Heavy Industries

Wharf

Serial turbine, substructure assembly and component port delivery due to depth, waves off coast

Navigation Channel and Wet Storage

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

Upland Yard

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

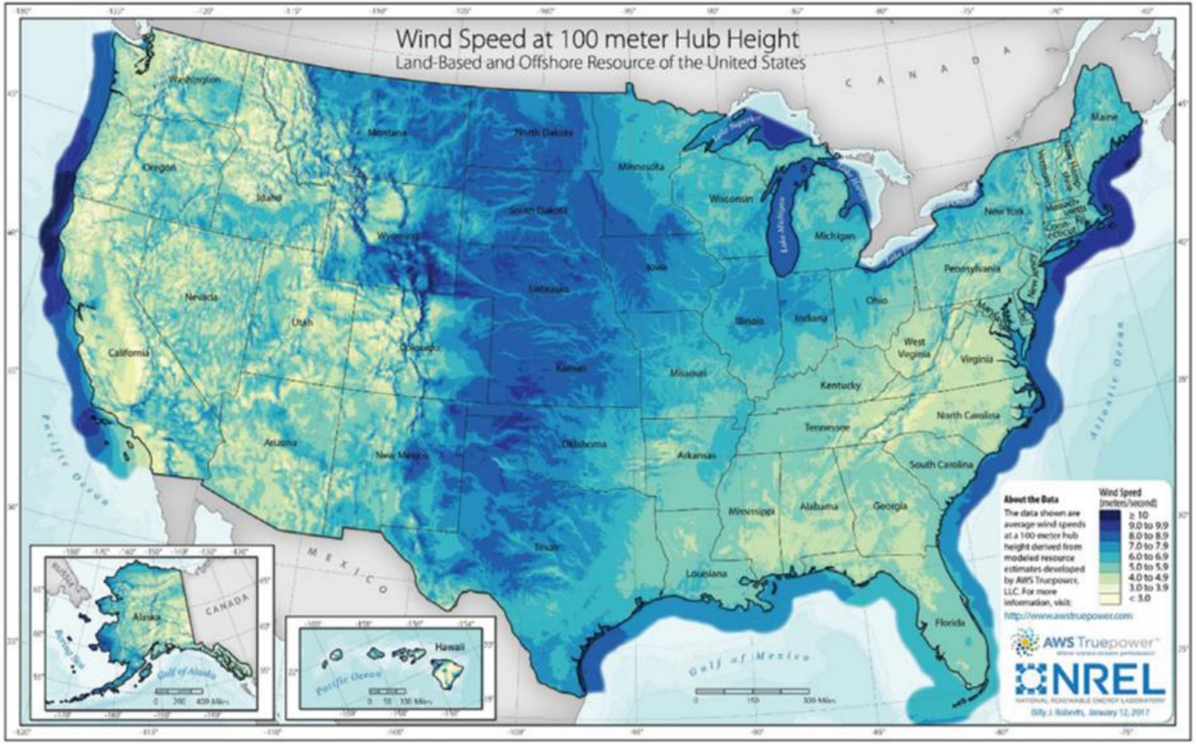
Crane

High lift capacity at 500 feet height to attach components

Crew Access & Maintenance

Moorage for crew access vessels. O&M berth for major repairs of full system

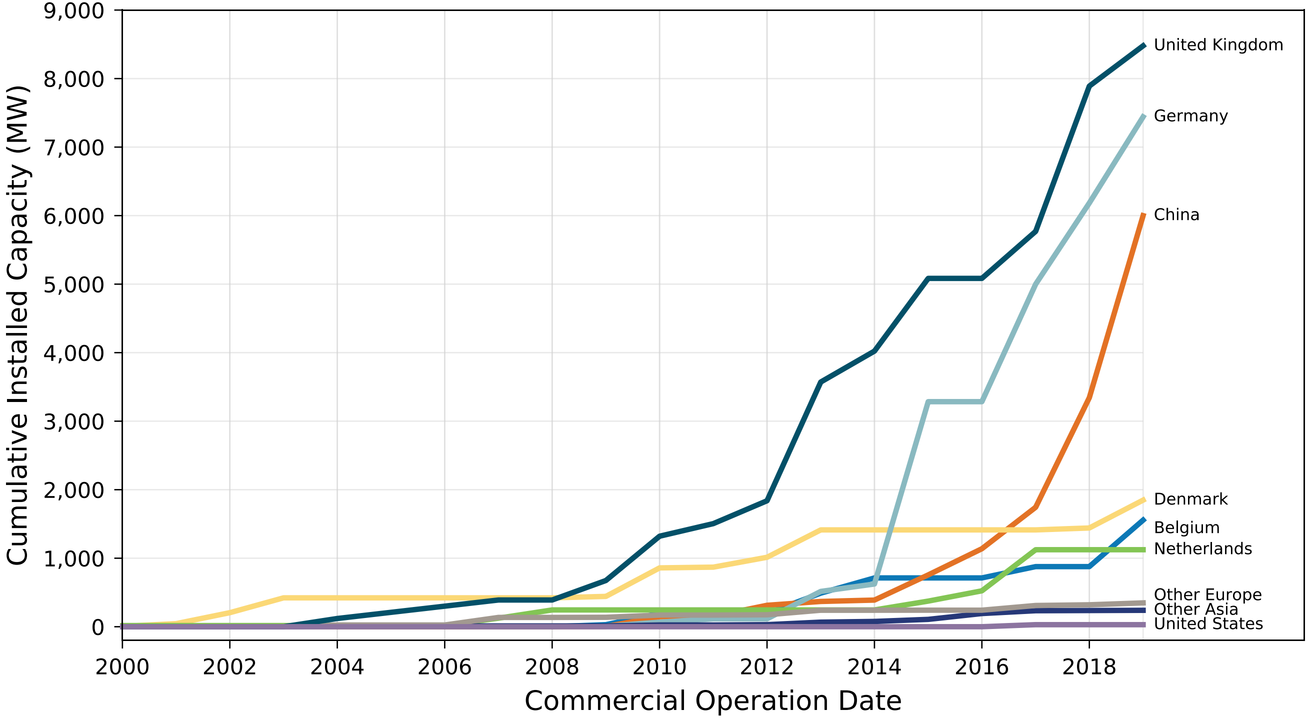
Why Pursue Offshore Wind Energy?



- ✓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

Cumulative Offshore Wind Installed Capacity by Country (January 1, 2020)



- 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

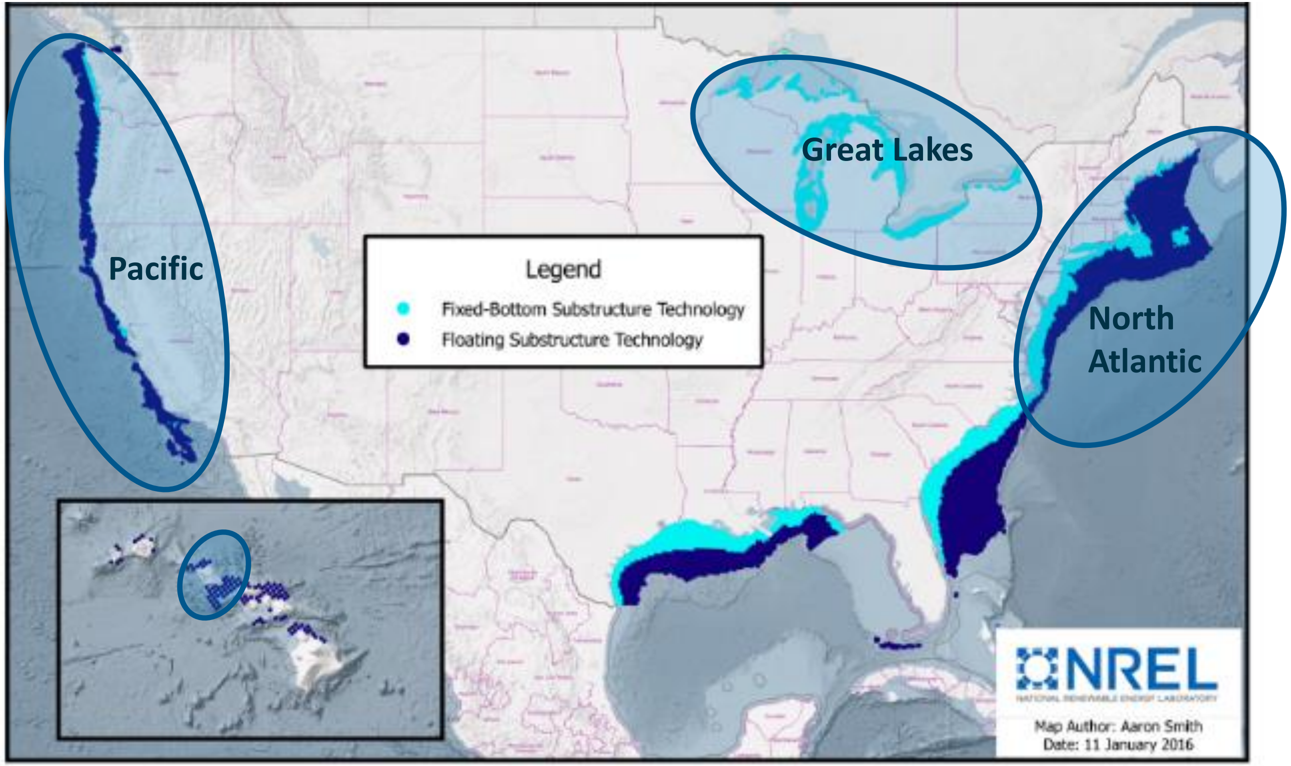


Figure credit: NREL

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

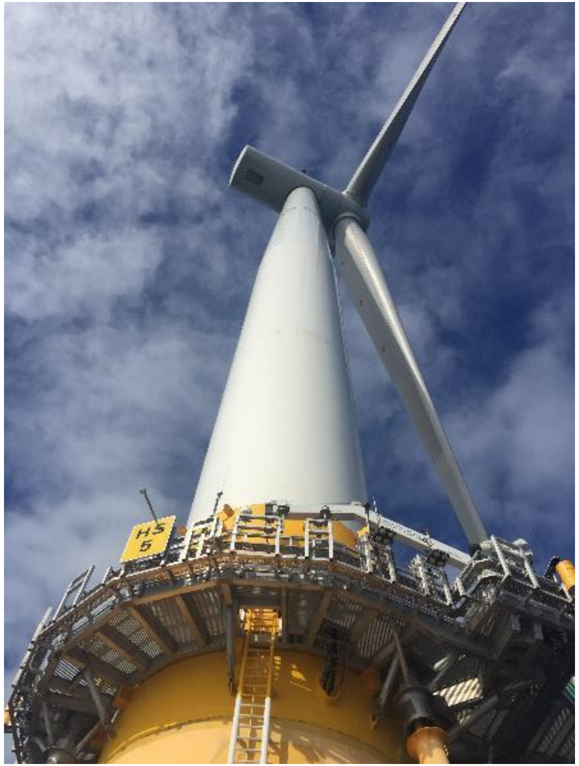
Oil and Gas Experience Helped Accelerate First Generation

- 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

Knowledge Transfer

Job Transfer

First Commercial Floating Wind Farm



Siemens 6-MW Wind Turbine at Hywind -2

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’)

Photo credit: Walt Musial

WindFloat Atlantic Floating Wind Farm

Vestas 8-MW Wind Turbine Being Towed to Station at Wind Float Atlantic

Source: Windplus/Dock90

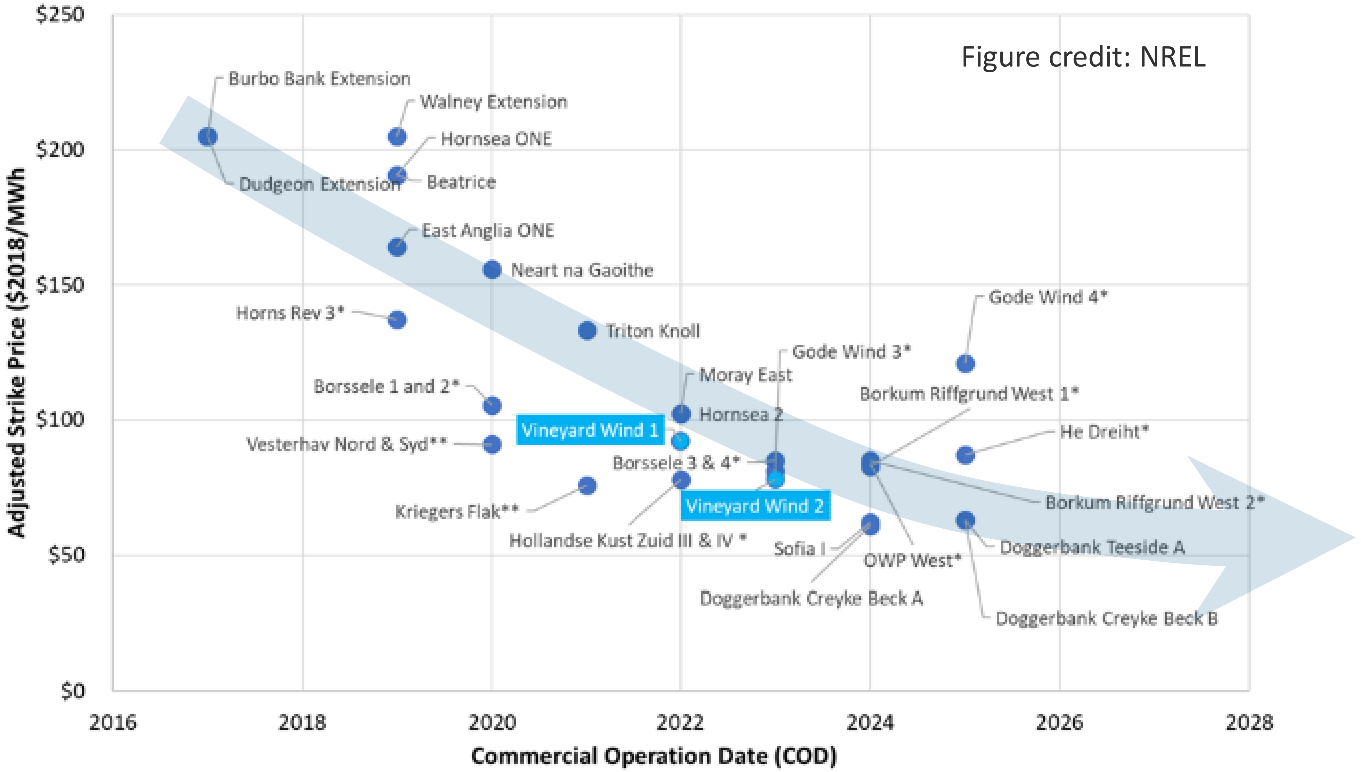
25-MW WindFloat Atlantic (2019)

- 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’)

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

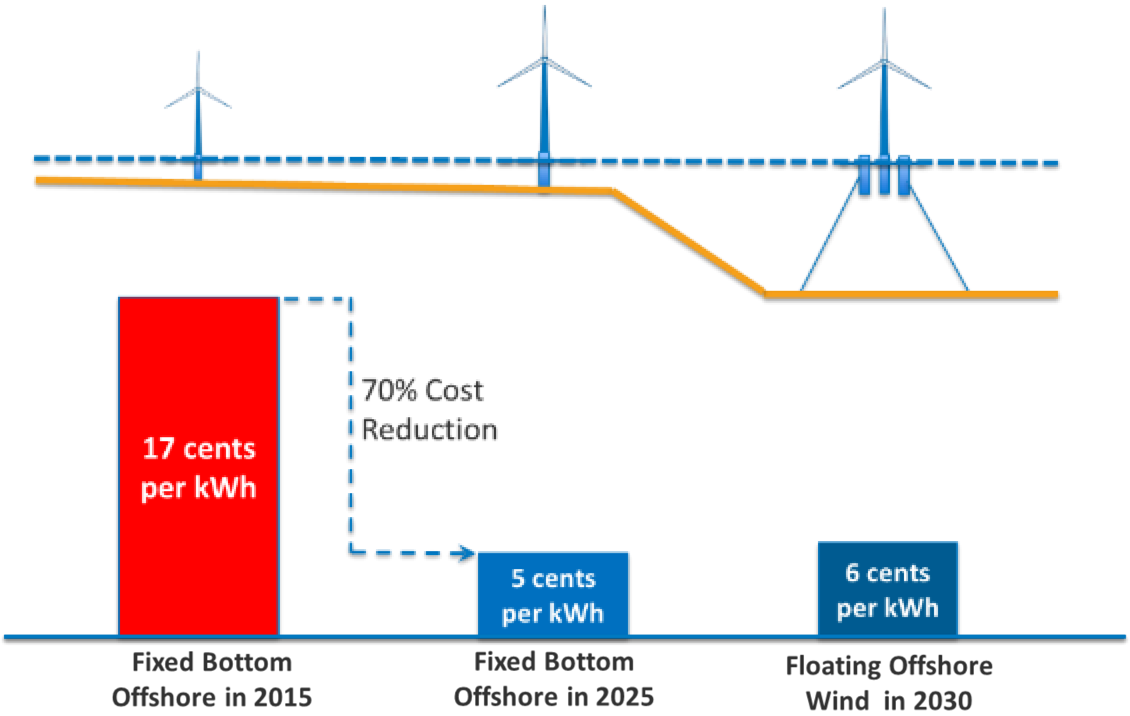
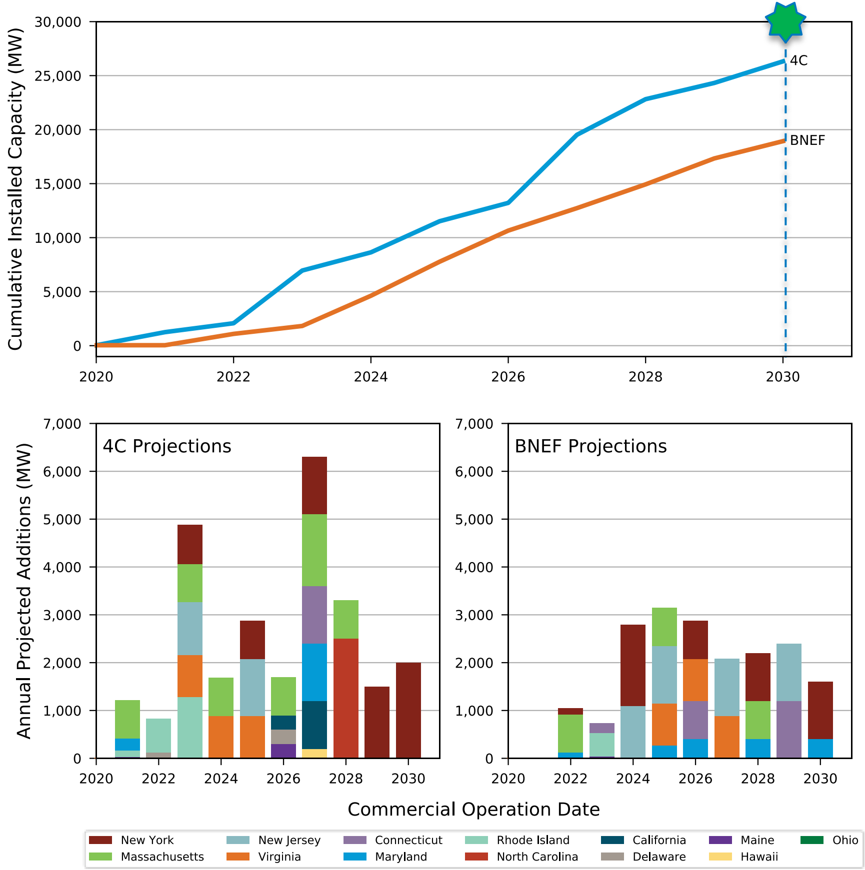


Figure credit: NREL

- 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

U.S. Offshore Wind Market Estimates Through 2030



- **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

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