NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Floating Offshore Wind Technology

BOEM Bureau of Ocean Energy Management

Gulf of Maine Intergovernmental Renewal Energy Task Force

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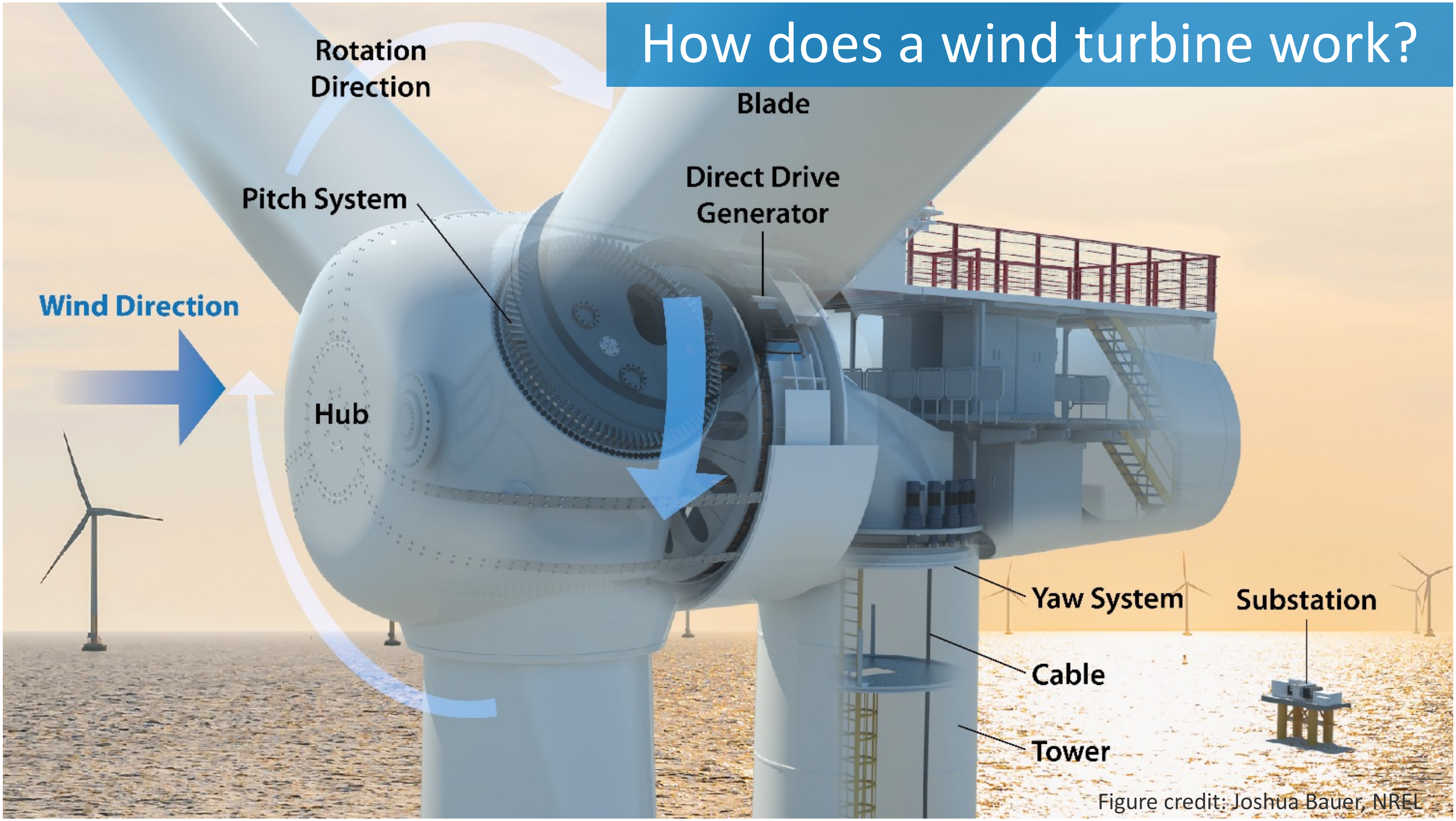

How does a wind turbine work?
Rotation Direction
Blade
Pitch System
Direct Drive Generator
Wind Direction
Hub
Yaw System
Substation
Cable
Tower
Figure credit: Joshua Bauer, NREL

Offshore Wind Turbines are Moving to 15-MW Scale

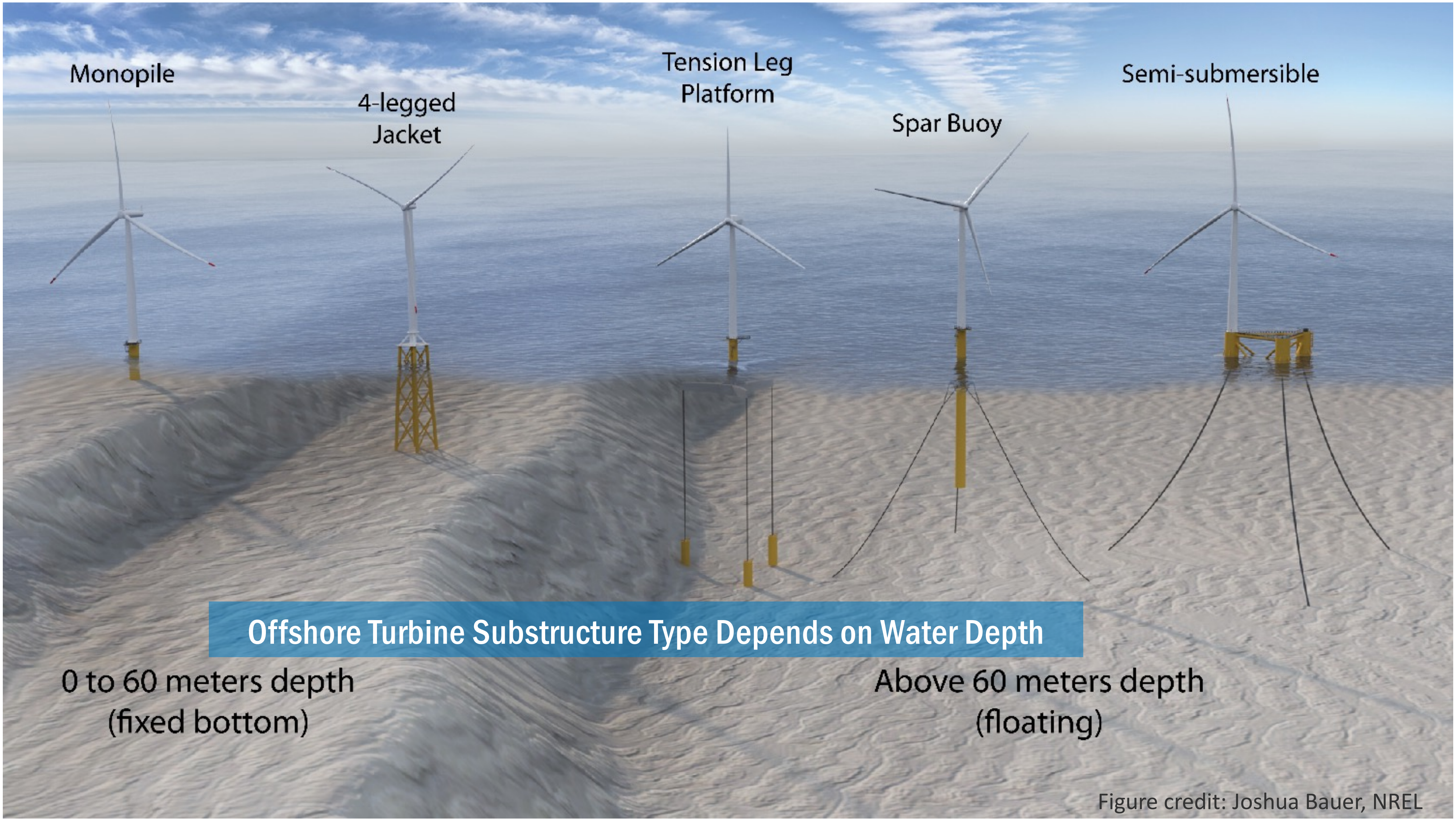
GE 12-MW Wind Turbine Nacelle

107-meter Blade for GE 12-MW Wind Turbine

Photos Courtesy of GE

- GE Upgraded the 12.0 MW (220-meter rotor) turbine to 14-MW in 2021
- Vestas V236-15.0MW produced its first power near the end of 2022
- Siemens Gamesa’s 14-236 DD prototype came online in early 2023

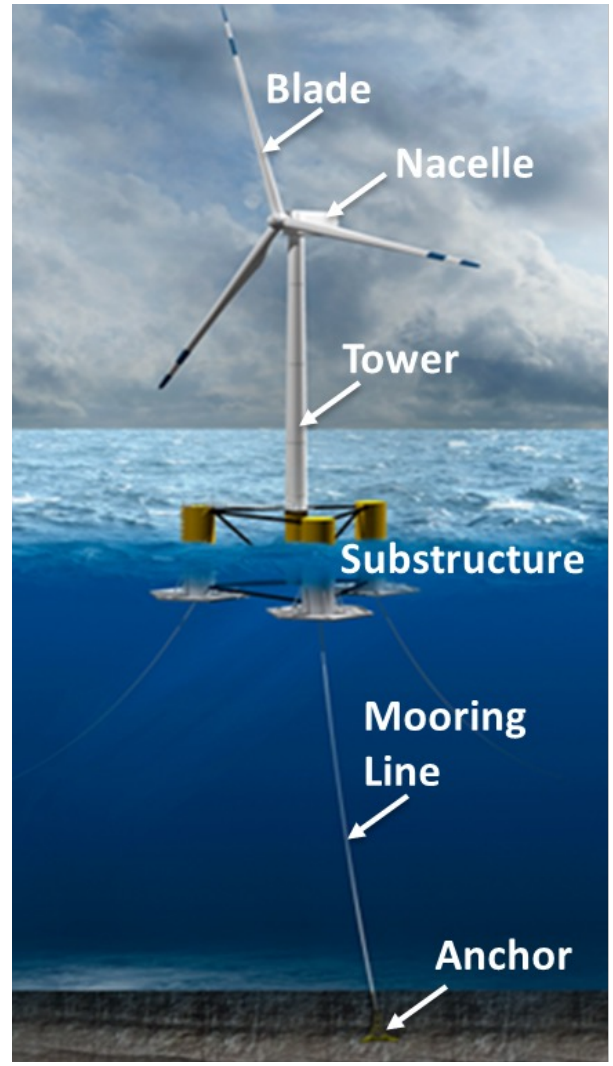
One 14-MW Haliade-X can supply the equivalent energy for up to 9,700 Maine households


Monopile
4-legged Jacket
Tension Leg Platform
Spar Buoy
Semi-submersible
Offshore Turbine Substructure Type Depends on Water Depth
0 to 60 meters depth (fixed bottom)
Above 60 meters depth (floating)
Figure credit: Joshua Bauer, NREL

Parts of a Floating Offshore Wind Turbine

Floating wind turbines look similar to *fixed-bottom offshore wind turbines* from the surface but are supported by buoyant substructures* moored to the seabed.

*The floating wind turbine *support structure* is comprised of the tower, substructure, mooring lines, and anchors



Parts of a Floating Offshore Wind Turbine

Characteristics of Basic Floating Platform Types

- **Spar:** Achieves stability through ballast (weight) installed below its main buoyancy tank
  - Challenges: Deep drafts limit port access
- **Semisubmersible:** Achieves static stability by distributing buoyancy widely at the water plane
  - Challenges: Higher exposure to waves; more structure above the waterline
- **Tension-leg platform (TLP):** Achieves static stability through mooring line tension with a submerged buoyancy tank
  - Challenges: Unstable during assembly; high vertical load moorings.

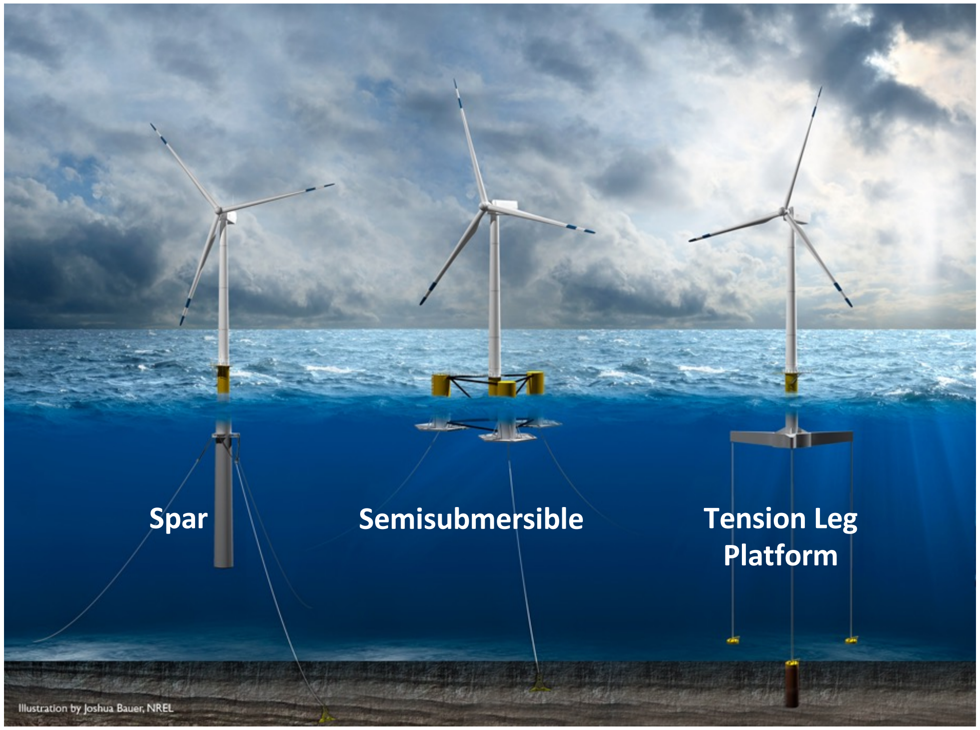
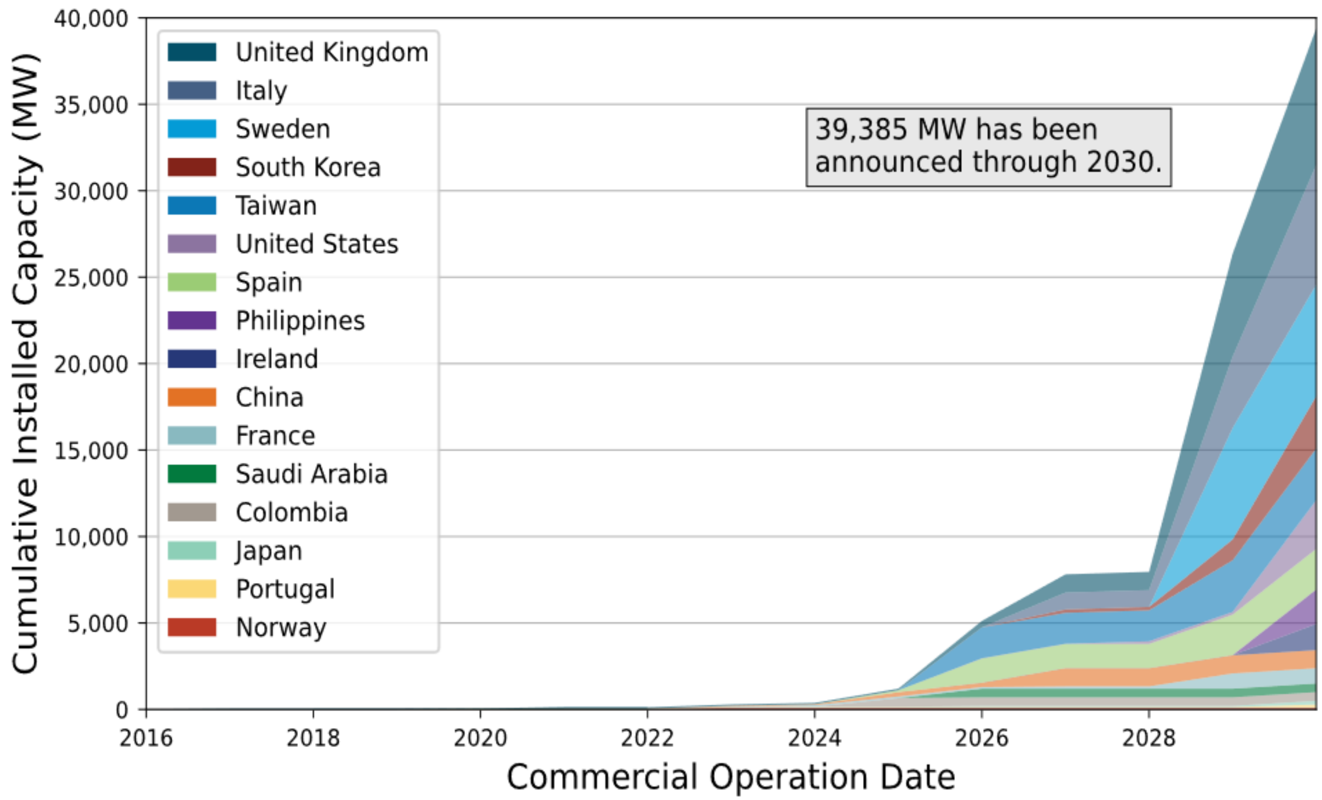


Figure credit: NREL

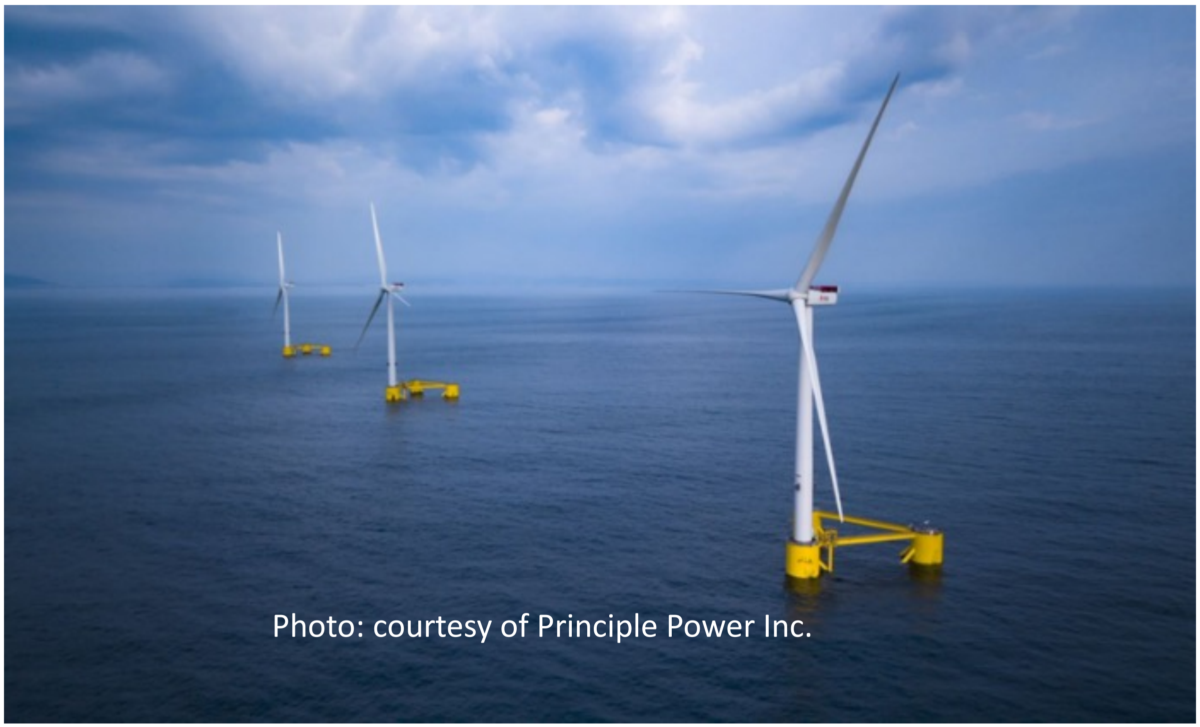
Floating Wind Energy Projects With Announced Operations Dates Worldwide

- Over 59,000 GW of fixed bottom offshore wind is operating.
- World-wide commercial expansion of floating wind expected about 2025.
- Over 39,000-Megawatts of announced projects by 2030.
- Industry forecasts indicate 10-13 GW may be more realistic for 2030.



European Floating Wind Projects

Kincardine 47.5-MW Floating Wind Plant (Scotland 2022)



Five Vestas 9.5-MW Wind Turbines

Hywind-2 30-MW Floating Wind Plant (Peterhead Scotland 2017)

Five Siemens 6.0-MW Wind Turbines

European Floating Wind Projects

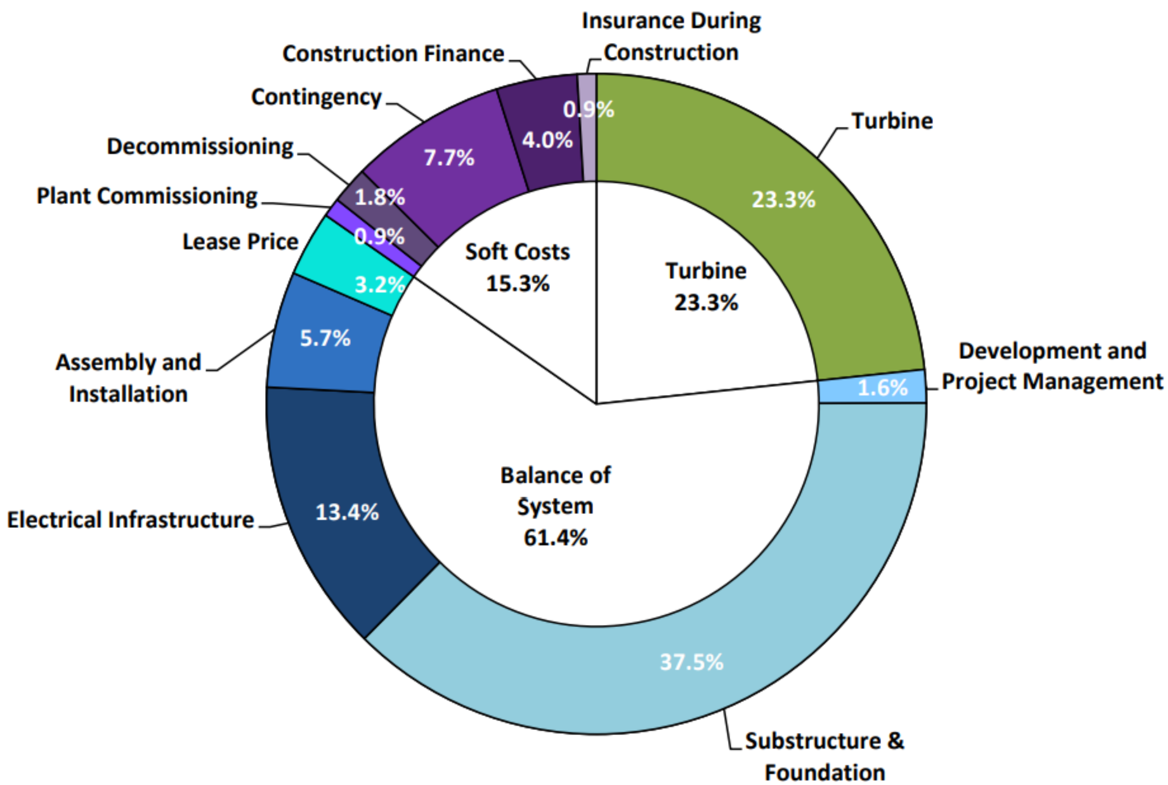
25-MW WindFloat Atlantic (Portugal 2019)

Three Vestas 8.4-MW Wind Turbines

TetraSpar 3.6-MW Floating Offshore Wind (Norway 2021)

Siemens 3.6-MW Wind Turbine

Cost Breakdown of a Floating Offshore Wind System

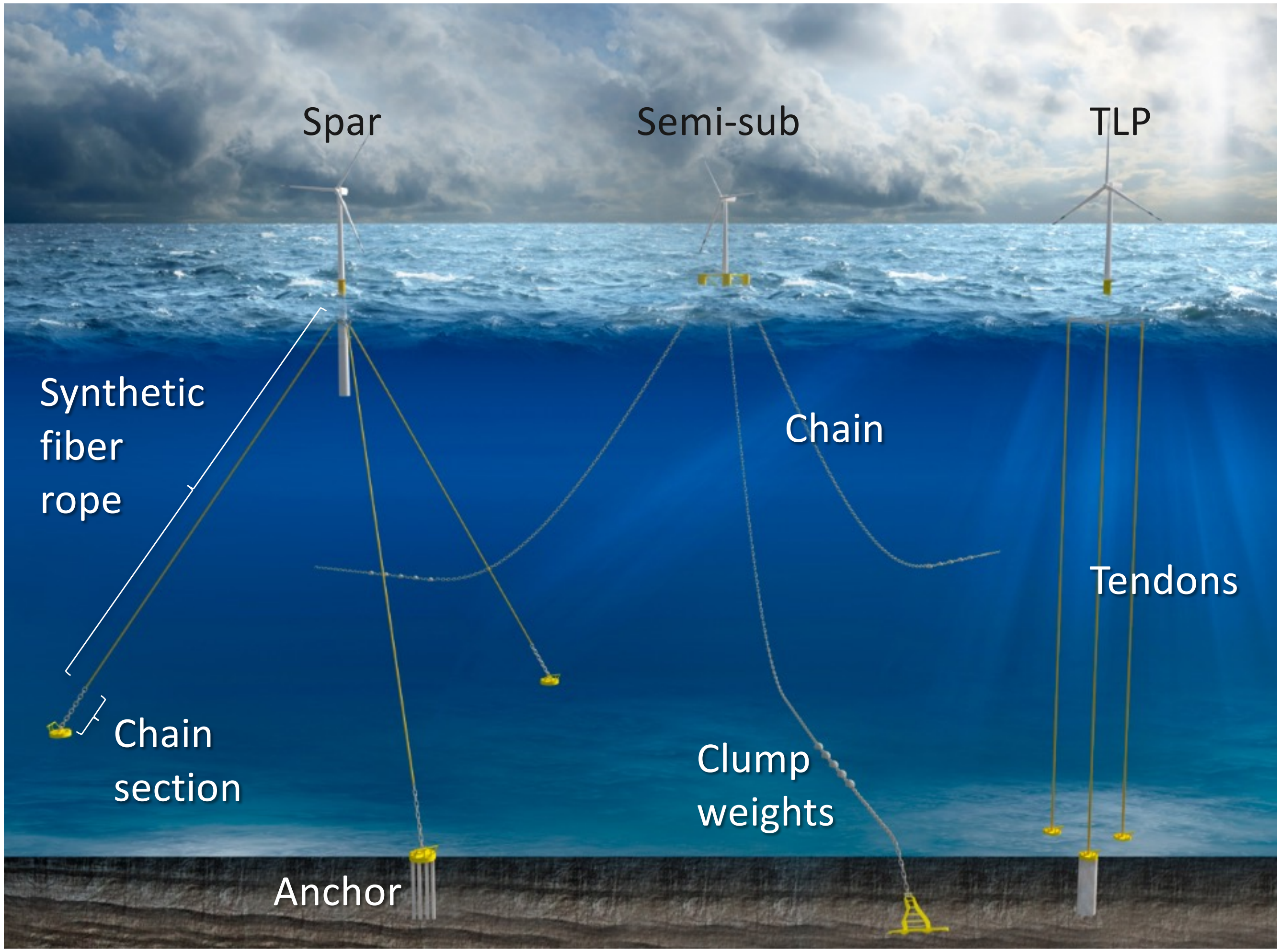


Floating Offshore Wind Capital Cost Breakdown

- The turbine cost is about 23.3%.
- Substructure and foundation cost is about 37.5%.
- Electrical infrastructure cost is about 13.4%.
- Assembly and installation cost is about 5.7%.
- Soft costs are about 15.3%
- Other costs are about 4.8%

Stehly, Tyler, and Patrick Duffy. 2022. *2021 Cost of Wind Energy Review*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy23osti/84774.pdf

Floating Wind Mooring Systems

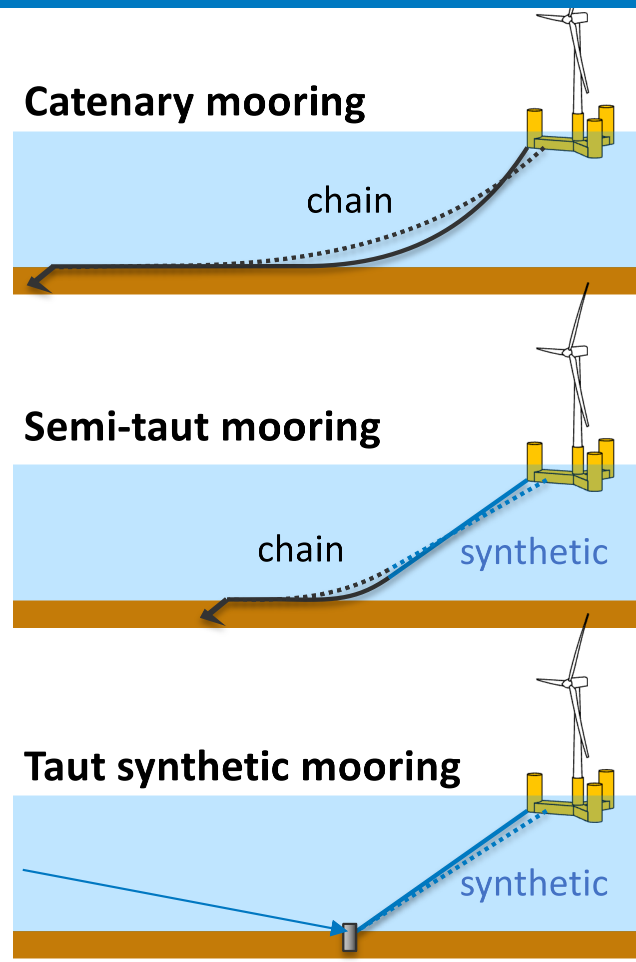


Adapting Mooring Systems for Co-existence with Fishing

Reducing Anchor Footprints

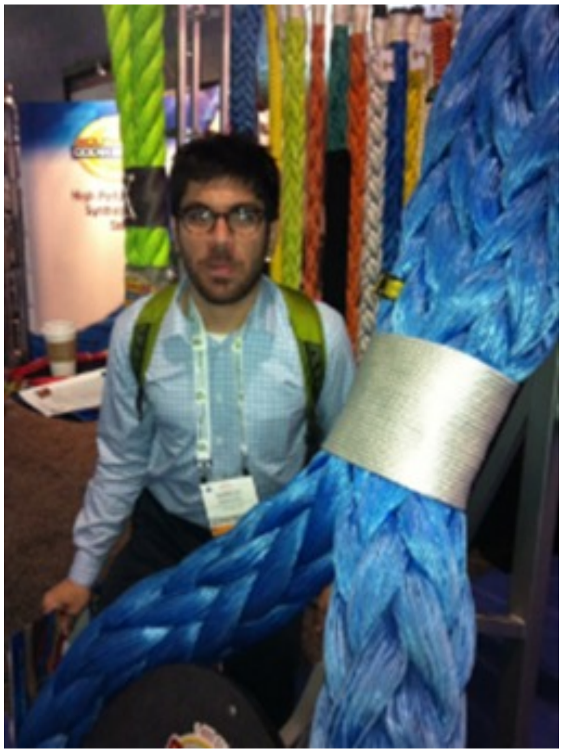
Line on seabed allows drag embedment anchors

Uplift at anchor requires suction piles or similar

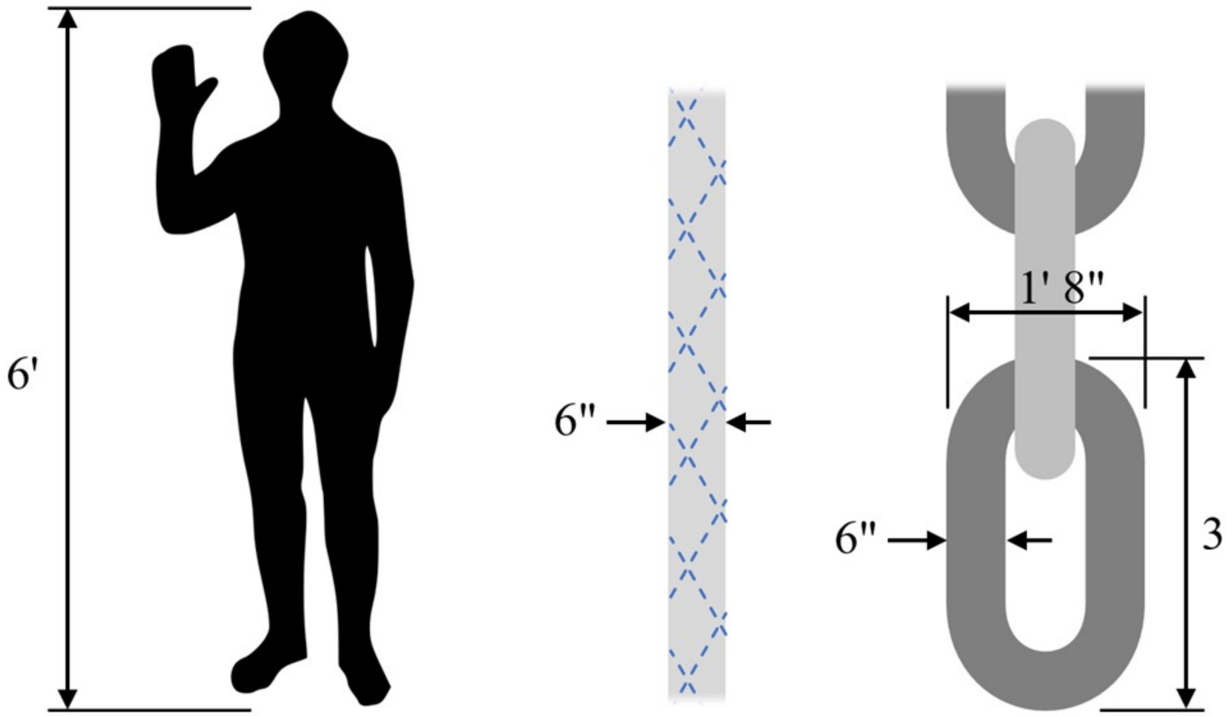


- **Catenary moorings** have the largest footprint but are the simplest.
- **Semi-taut moorings** significantly reduce the anchor distance from the turbine without changing anchor types or substructure design.
- **Taut moorings** reduce the anchor circle by more than 50% but require vertical load anchors and more complex design changes.

Mooring Lines are Heavy and Thick



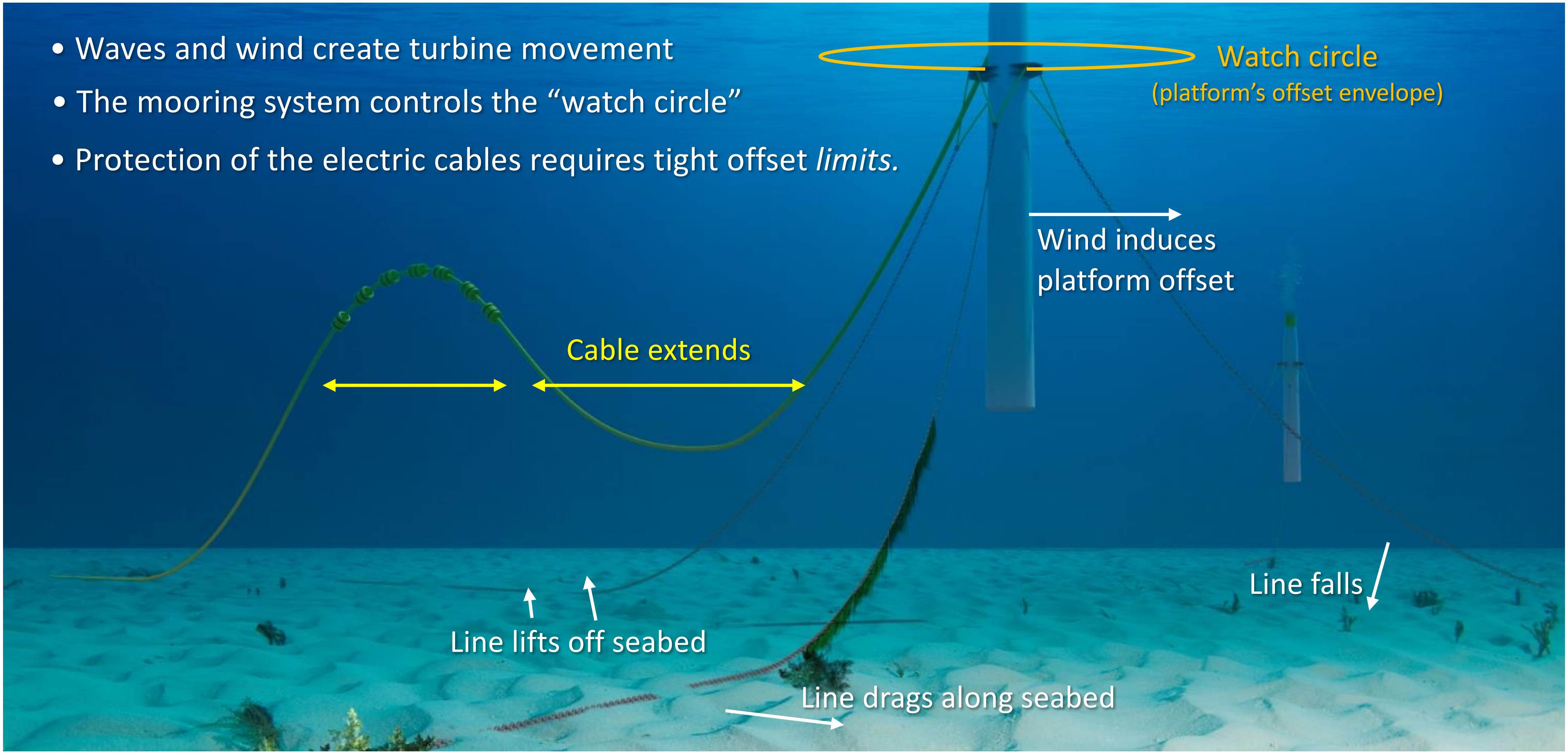
Rope Materials – Polyester, Nylon, Polypropylene. (Photo: Walt Musial)



Comparison of the size of a person (left) next to representative sections of mooring rope (middle) and a mooring chain link (right). Image by Matt Hall, NREL

The Underwater View

- Waves and wind create turbine movement
- The mooring system controls the “watch circle”
- Protection of the electric cables requires tight offset *limits.*



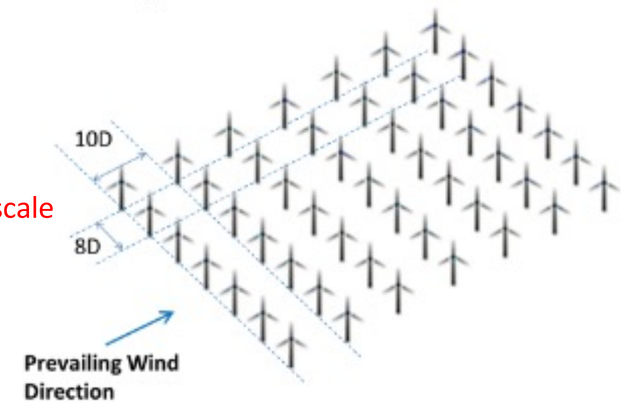
Floating Offshore Wind Substations

- Offshore substations or electric service platforms collect AC power from all turbines across a wind power plant at 66 kilovolts (kV) or greater.
- High-voltage transformers step up the voltage to 220 kV and export power to shore through buried subsea cables.
- Substations are attached to the seabed with floating substructures.
- Export cable lengths greater than about 50 miles will use high voltage direct current systems to reduce losses and cost.

Photo from Siemens, 27865

Turbine Spacing Increases With the Rotor Diameter

Turbine spacing shown is not to scale



- Typical spacing 6-8 rotor diameters
- Larger turbine spacing = fewer turbine positions but lower wake losses
- Turbine spacing is independent of anchor spread
- Lease area energy yield may be greater with tighter spacing but with diminishing returns and higher costs.

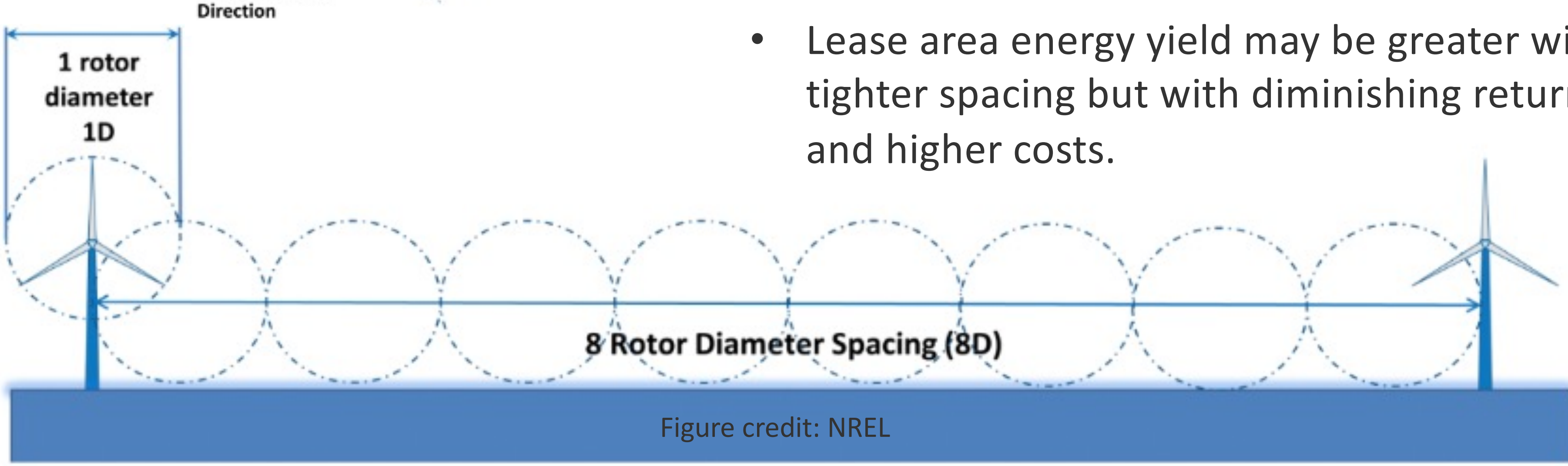


Figure credit: NREL

Example: GE 14-MW Haliade-X turbines with a 220-m rotor would be spaced over 1 mile apart

Floating Offshore Wind Commercial Port and Infrastructure Requirements

Photo Rendering of Future Salem Offshore Wind Terminal. Source: Crowley

Wharf

Length and draft must accommodate serial turbine/substructure assembly and delivery – (e.g., one unit per week)

Navigation Channel and Wet Storage

Storage and wet-tow out of assembled turbines with year-round access. Nominal width/depth about 100-m/8-m minimum

Upland Yard

30 – 100+ acre storage and staging of blades, nacelles, towers, possible fabrication of floating substructures

Crane

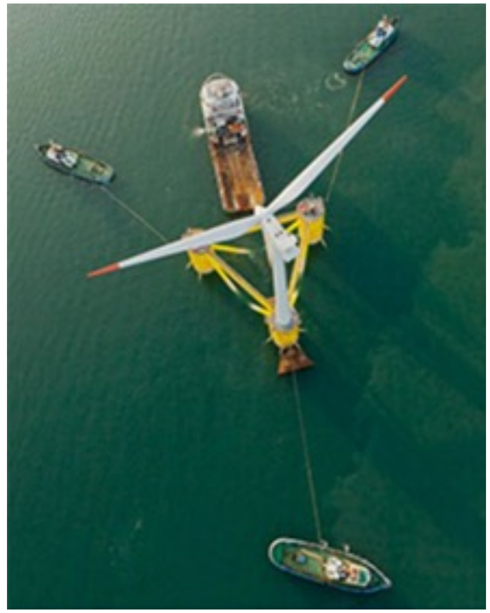
Minimum 800-ton lift capacity at 500 feet height to attach components

Crew Access & Maintenance

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

Floating Wind Project Vessels – Installation Phase

- No heavy lift foundation vessels, WTIVs and feeder barges.
- No rock dumping vessels for scour protection
- Larger fleet of small vessels
- Vessel spread suited for deeper waters.



https://www.vanoord.com/en/equipment/cable-laying-equipment/

Cable Lay Vessel

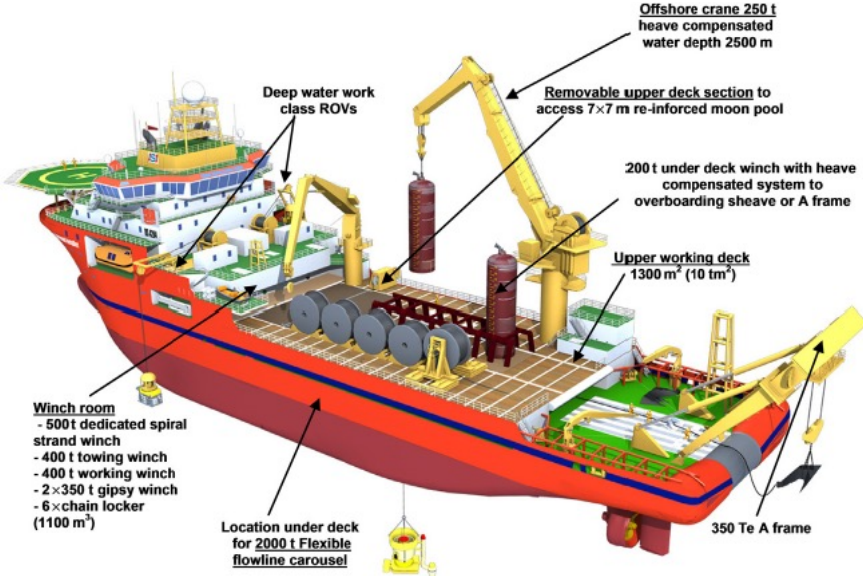
https://www.solstad.com/wp-json/solstad/api/vessel/367/pdf

Anchor Handling Tug Supply

https://www.onesteppower.com/post/how-do-tugboats-work

Tugboats

Suction Pile Anchor Installation



Floating Wind Project Vessels Operations Phase

- Tow to shore for large component repair
- Service in place for smaller repairs
- Service Operation Vessel (SOV) far shore projects
- Crew Transfer Vessels (CTV) near shore projects
- Autonomous fleet emerging for inspections, surveys, data gathering

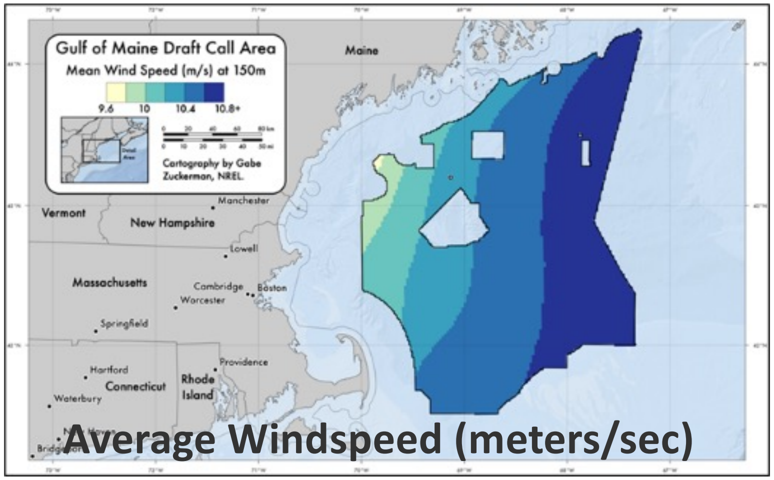
Boskalis AHT Manta (Kincardine)

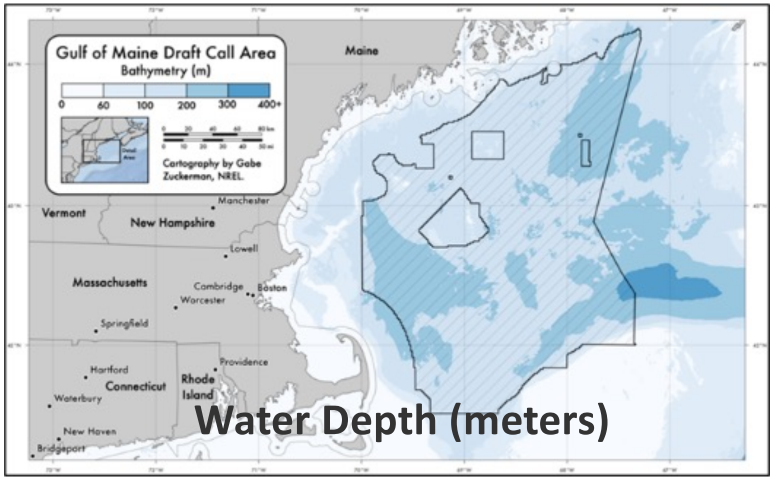

Boskalis AHT Manta (Kincardine)

Bourbon AHTS Orca (WindFloat Atlantic)

Consequences of Siting Projects Farther from Shore

Negative Factors with Greater Distance to Shore	Positive Factors with Greater Distance to Shore
• Operational expenditures increase	• Higher energy yield potential
• Export cable cost increase	• Efficiencies with Possible multi-GW plant aggregations
• Installation costs turbine, cables, substation increase	• Lower conflicts with commercial fishing
• Higher emissions from ships	
• Greater exposure to whales	
• Increase turbine downtime	
• Higher electrical losses	
• Increased safety risk to crews	

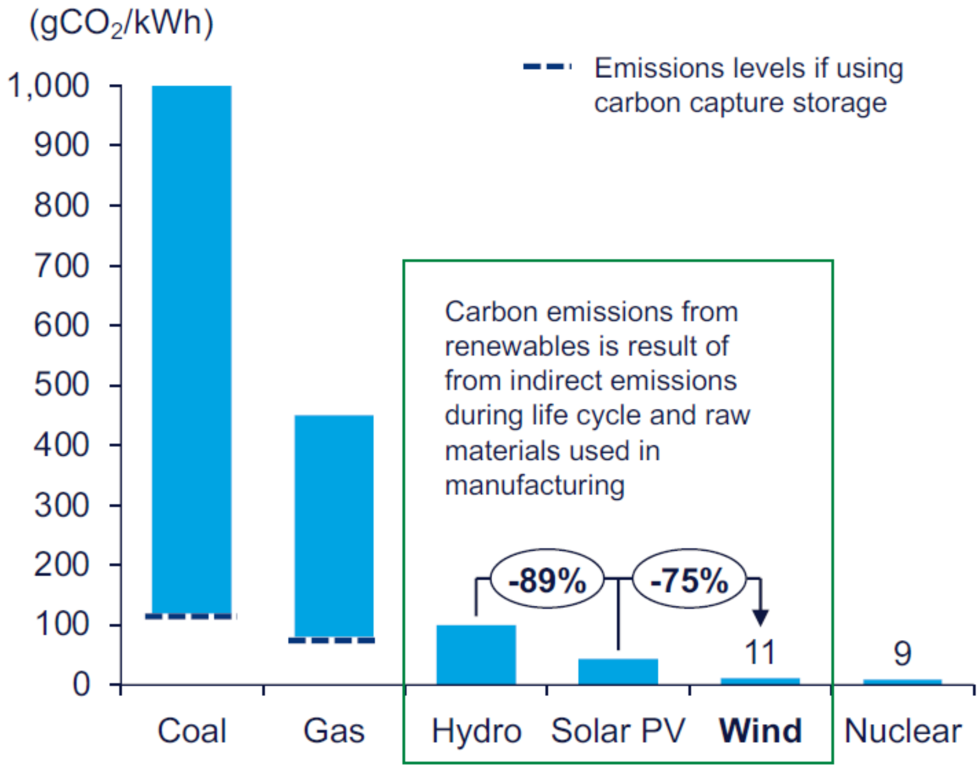




Wind power is still one of the lowest emitters of all power technologies

No power technology has achieved being carbon neutral over its life cycle but wind power has the potential to reach that possibility ahead of other technologies

Life cycle CO_2 emissions by technology type



- All types of mainstream power generation technologies result in carbon emissions over its life-cycle
- **Within renewable energy, wind power has the lowest life cycle carbon emissions** with indirect emissions derived from raw material extraction and manufacturing of:
  - » Steel (in the turbine nacelle, tower, rotor and hub)
  - » Concrete (if inclusive of the foundations used to hold the turbine) in a wind power plant
- **Only nuclear power has a lower carbon lifecycle** than wind power but capex costs per MW can be 2-3 times more than solar and wind power plants
- Major global turbine suppliers have already reached carbon neutral in operations with plans to decarbonize life cycle emissions in the long term (see slide 13)
- **Reductions will largely come from greening of wind power supply chain** instead of buying third party offsets

Source: Wood Mackenzie, IEA

Key Takeaways

- Offshore wind in the Gulf of Maine will use floating wind turbines
- 80% of the global offshore wind resources are suited for floating offshore wind energy. Gulf of Maine has some of the best in the world.
- Floating offshore wind is expected to be deployed at utility-scale by 2025 but has been proven at the 30-MW to 50-MW scale.
- Mooring systems with smaller anchor footprints are under development to maximize co-existence with fishing.
- Custom ports and vessels will be key to offshore wind development in the Gulf of Maine
- Wind energy is among the lowest carbon emitters on a life cycle basis.

Thank you for your attention!

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Photo Credit : Dennis Schroeder-NREL