Floating Offshore Wind Technology

for the Gulf of Maine

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How does a wind turbine work?

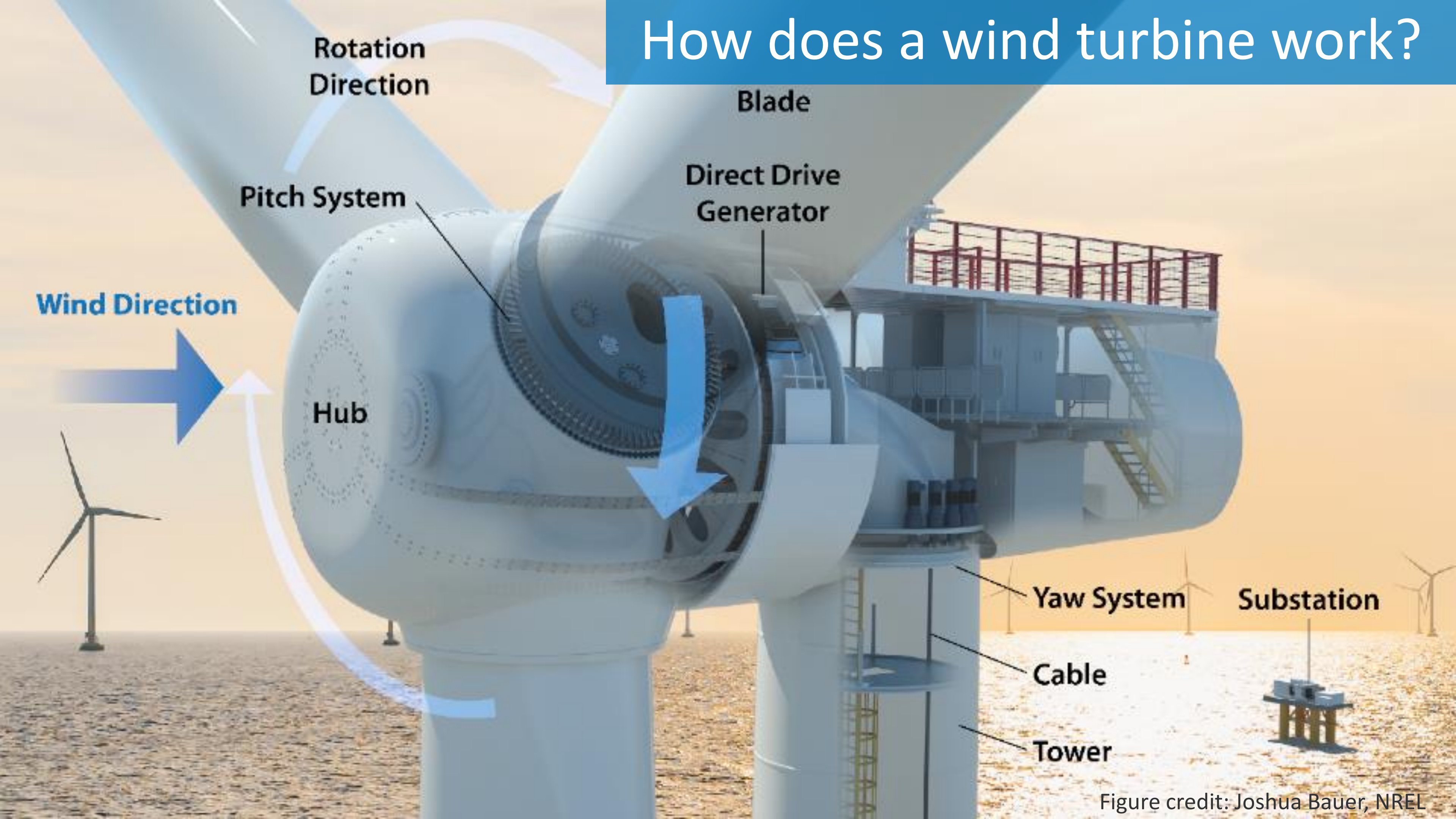


Figure credit: Joshua Bauer, NREL

Offshore Wind is Starting a New 15-MW Scale Technology Platform

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 – Replacing with GE Vernova 15.5 MW "Workhorse"
- Vestas V236-15 MW 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 used by 9,700 Maine households

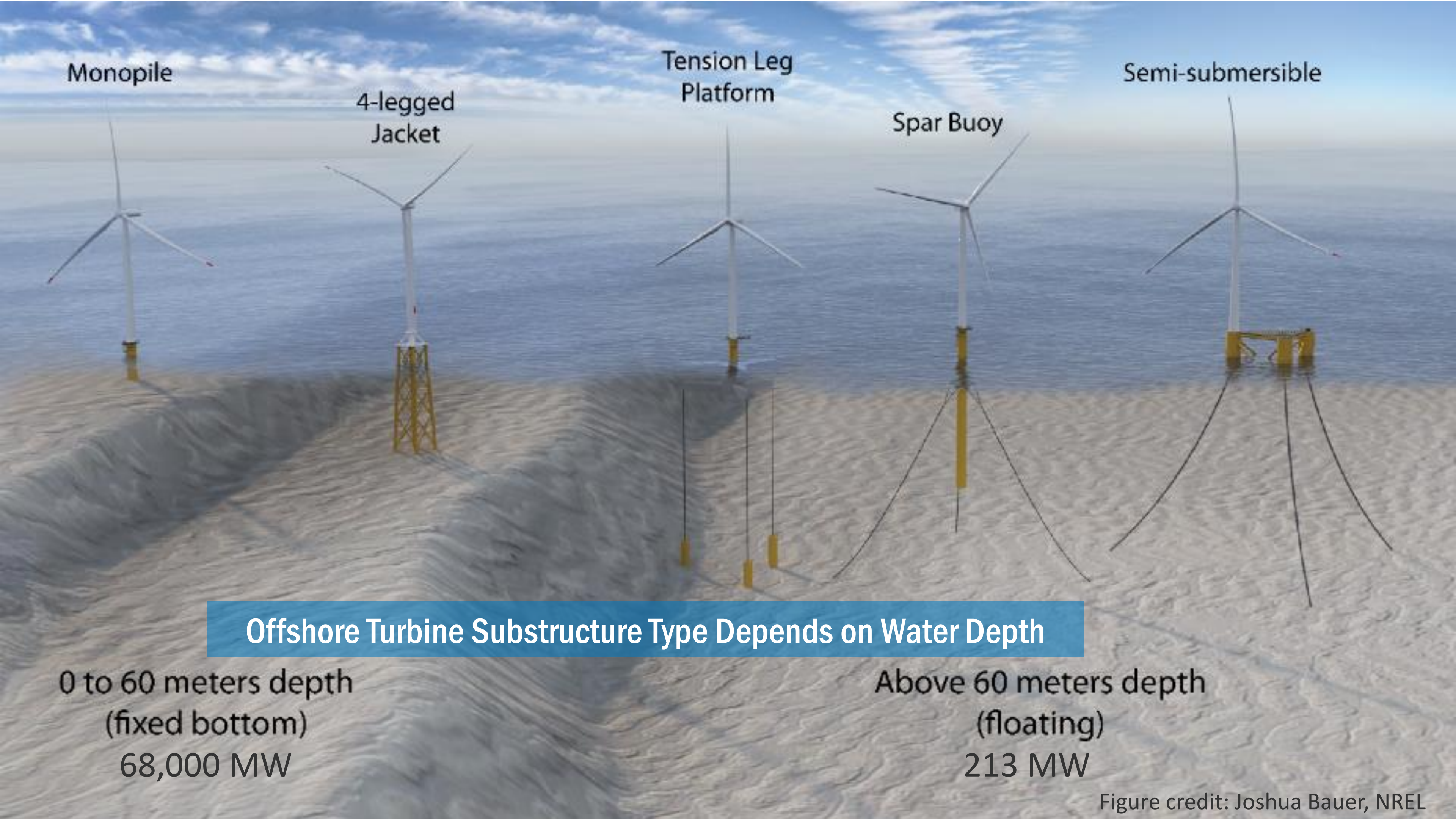
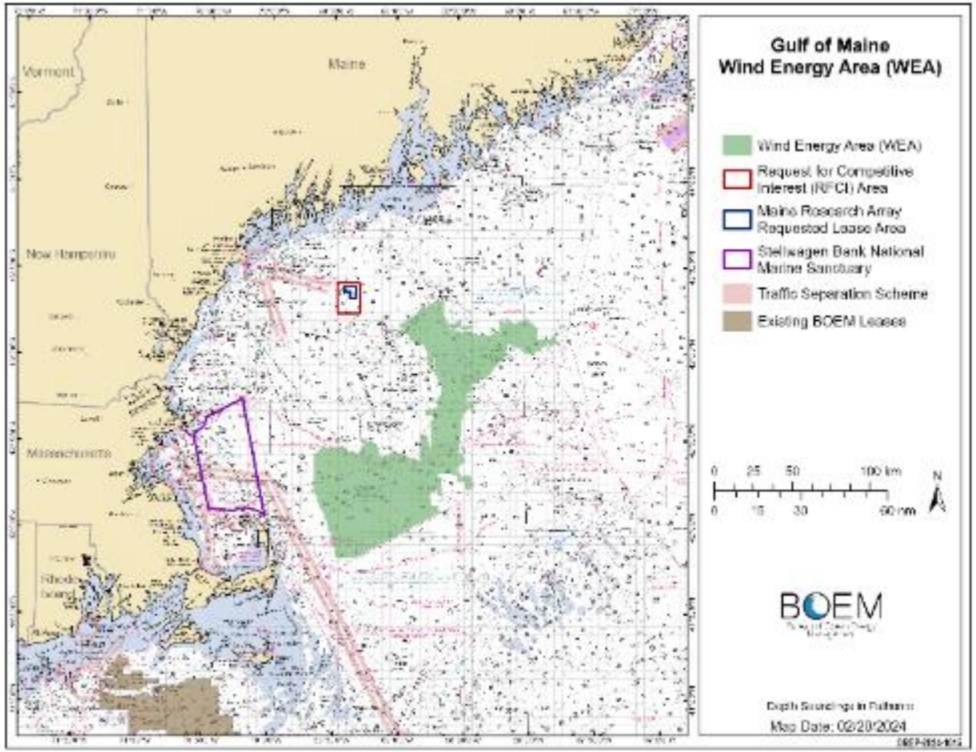


Figure credit: Joshua Bauer, NREL

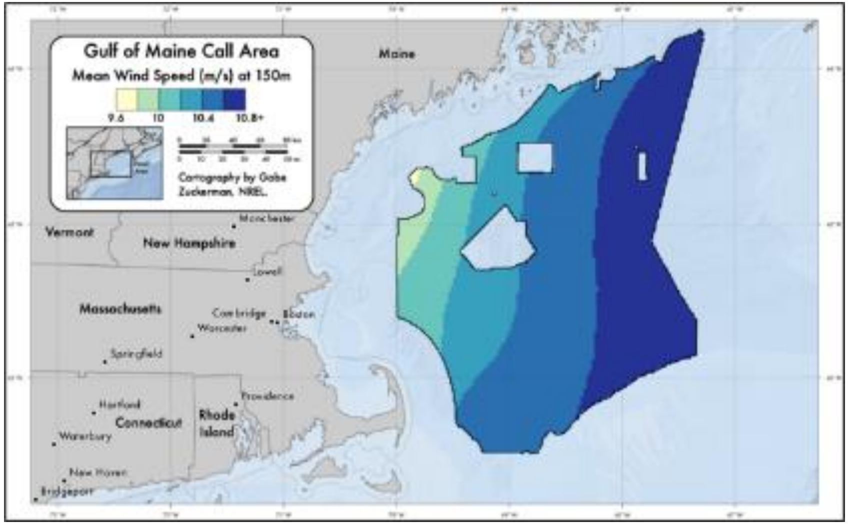
Gulf of Maine Wind Energy Area

- On March 15, 2024, BOEM designated the Final Wind Energy Area (WEA) in the Gulf of Maine.
- The Final WEA is about 2 million acres, an 80% reduction from the original Call Area.
- The Final WEA has the potential to support 32 GW of offshore wind capacity.
- WEA capacity exceeds current state goals:
  - 10 GW for Massachusetts
  - 3 GW for Maine.
- The excess capacity will allow BOEM to consider additional deconfliction and allows for future rounds off leasing.
- ISO-NE planning targets are for 18 GW.



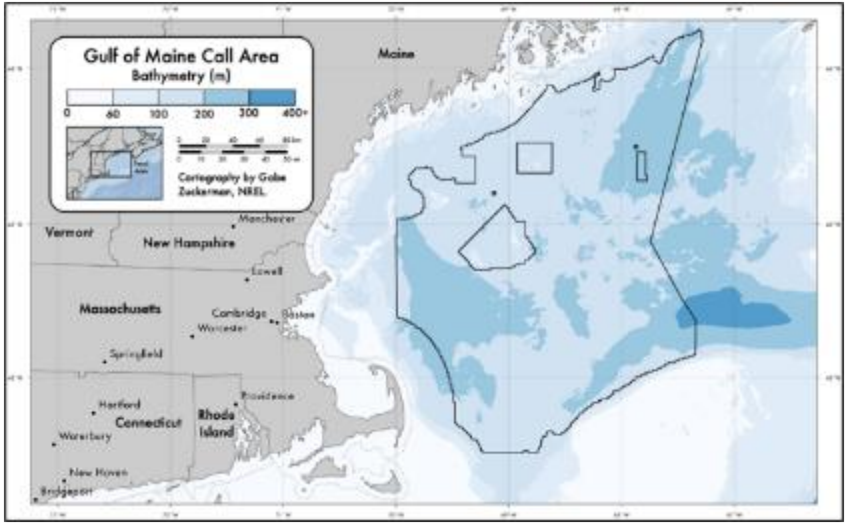
Gulf of Maine Wind Speeds and Water Depths

Average Annual Wind Speeds



Average wind speeds in the Gulf of Maine WEA are estimated at a 150-meter (m) elevation between 9.8 m/s and 10.6 m/s.
Image from NREL

Water Depths



Water depths in the Gulf of Maine WEA are between 150-m and 300-m
Image from NREL

Regulatory Process for Offshore Wind in the United States

Figure from BOEM/BSEE
https://www.bsee.gov/about-bsee/renewable-energy

Bureau of Ocean Energy Management

Bureau of Safety and Environmental Enforcement

Offshore Wind Leasing Process – Key Decision Points and Timelines

Developer Obtains Exclusive Site Control

Port and Infrastructure Development

Power Offtake Agreement

2-5 Years

2-3 Years

BUILD

2-3 Years

Commercial Operations

25-35 Years

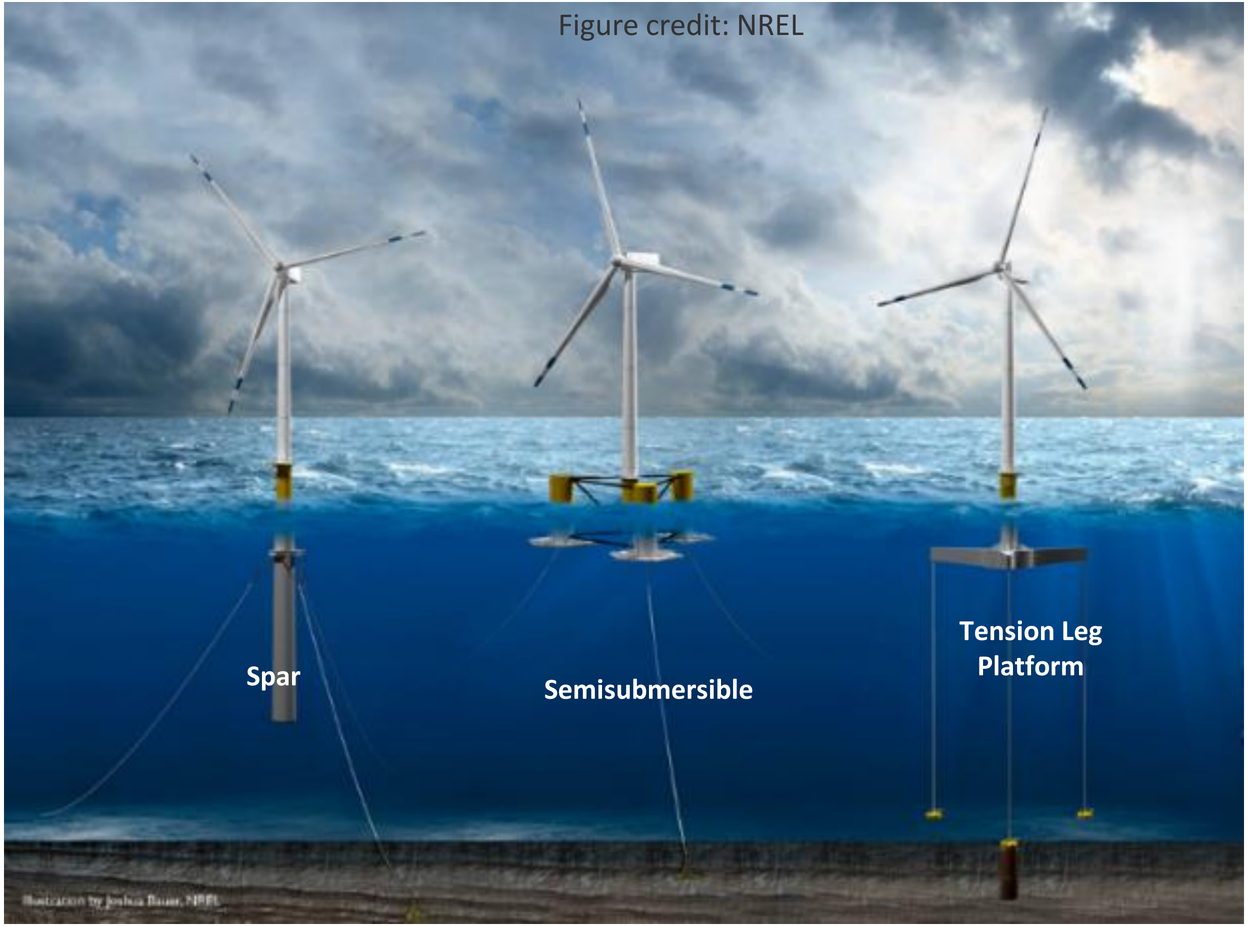
Figure Adapted from BOEM/BSEE https://www.bsee.gov/about-bsee/renewable-energy

Gulf of Maine Leasing Process as of April 3, 2024

Construction and Operations Plan (COP) and Power Offtake contract lock in key variables like turbine size, turbine layout, projects size, foundation type, Safety Management System

FIR/FDR: Final design and installation details –: turbine type, anchor type and exact locations, installation plan. Power offtake agreement is needed to obtain financing

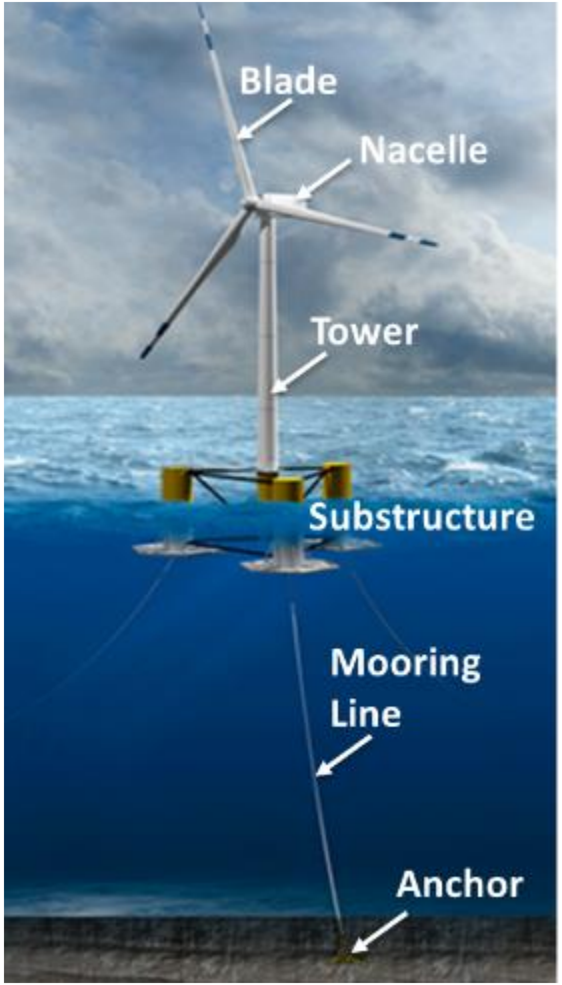
Basic Floating Platform Types



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 Semi-submersible Floating Platforms

Semisubmersible: Achieves static stability by distributing buoyancy widely at the water plane

- Advantages:
  - Stable during assembly and tow out
  - Low draft provides highest accessibility to conventional ports
  - Most operating experience (PPI)
- Challenges:
  - Higher exposure to waves
  - Heavier - more structure above the waterline
  - Dependence on foreign steel
  - Industrialized mass production
- Mitigations
  - Concrete designs

Figure credit: NREL

European Floating Wind Projects – Semi-submersible

Kincardine 47.5-MW Floating Wind Plant (Scotland 2022)

Five Vestas 9.5-MW Wind Turbines

25-MW WindFloat Atlantic (Portugal 2019)

Three Vestas 8.4-MW Wind Turbines

Characteristics of Spar Buoy Floating Platforms

Spar Buoy: Achieves stability through ballast (weight) installed below its main buoyancy tank.

- Advantages:
    - Simplicity
    - Very stable during operation and without mooring lines
    - Demonstrated in North Sea (Equinor)
- Challenges:
    - Deep drafts limit port access and siting options.
    - Industrialized mass production
- Mitigations
    - Hybrid solutions that allow quayside assembly and commissioning with deployable ballast weight (Stiesdal Offshore Wind)
    - Tilting concepts

Figure credit: NREL

European Floating Wind Projects – Spar Examples

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

Five Siemens 6.0-MW Wind Turbines

TetraSpar 3.6-MW Floating Offshore Wind (Norway 2021)

Siemens 3.6-MW Wind Turbine

Characteristics of TLP Floating Platforms

Tension-leg platform (TLP): Achieves static stability through mooring line tension with a submerged buoyancy tank.

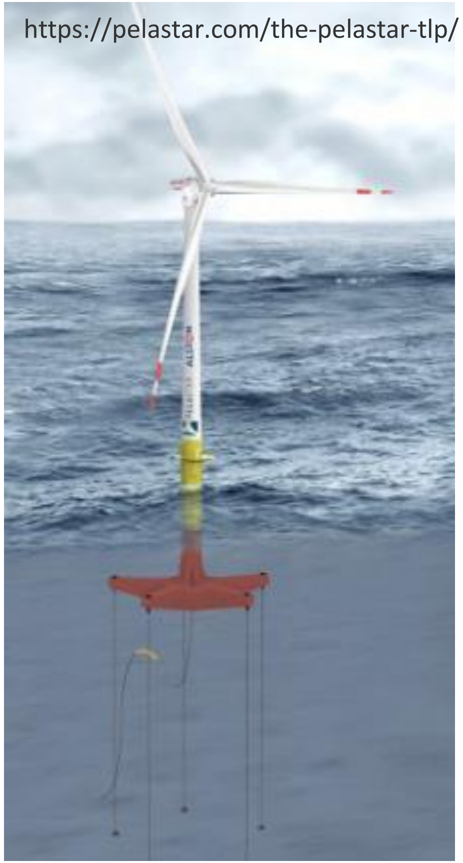
- Advantages:
  - Very stable during operation
  - Smallest footprint on the seabed
  - Light weight substructures
- Challenges:
  - Unstable during assembly without additional buoyancy
  - High load vertical moorings (expensive)
  - Some dependence on foreign steel
  - No operating experience in offshore wind energy
  - Industrialized mass production
- Mitigations
  - Hybrid designs that allow stable assembly at quayside.
  - Concrete designs

Figure credit: NREL

Tension Leg Platforms

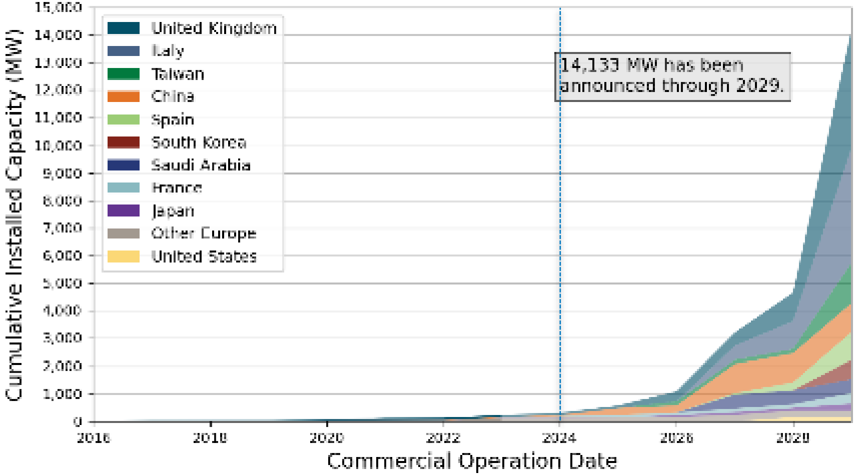
- Tension Leg Platforms have not yet been demonstrated for offshore wind.
- SBM Tension Leg Platform was developed for the Provence Grand Large floating offshore wind farm. When completed it will provide 24 MW of power to the French grid. Turbines were installed in October 2023 (left image).
- Glosten's Pelestar, Seattle, WA has advanced over the past decade (right image).
- Many other TLP designs have been proposed.

SBM TLP Provence Grand Large floating wind farm – expected 2024.

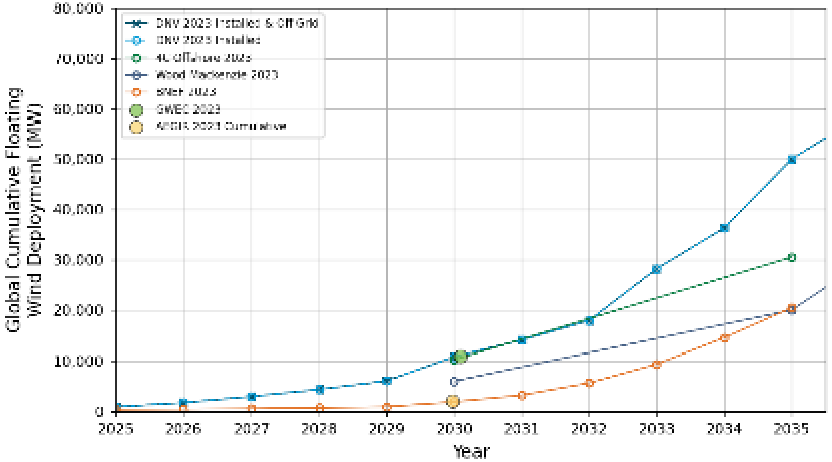


https://pelastar.com/the-pelastar-tlp/

World-wide Floating Wind Energy Market Projections



Projections based on developer announcements

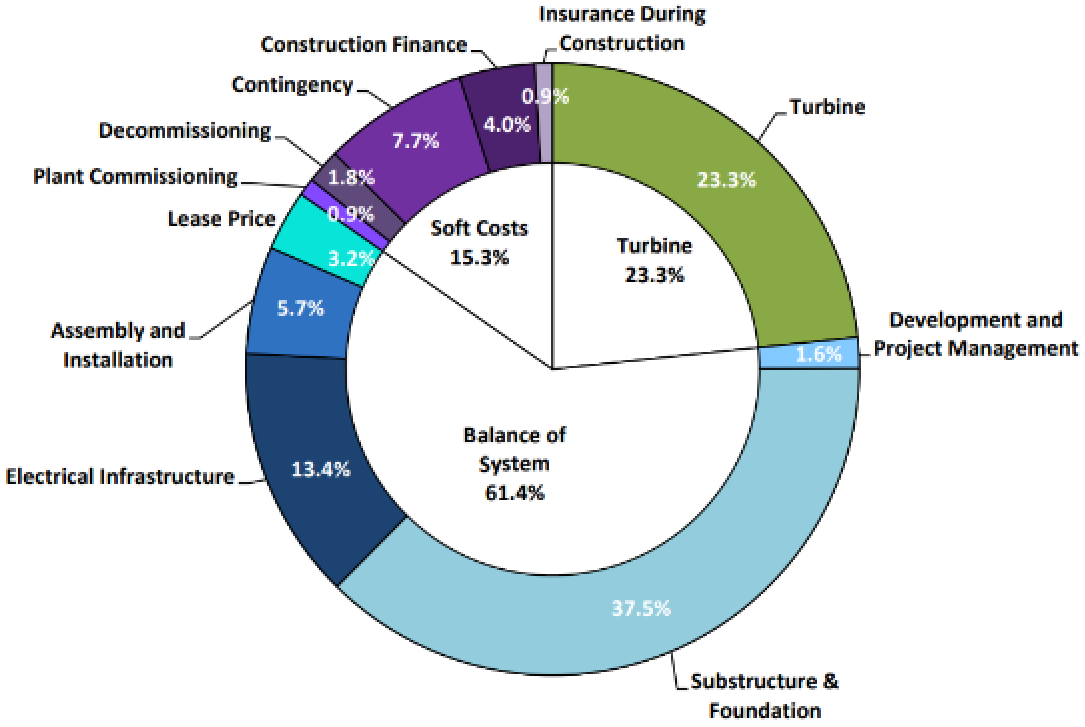


Projections based on industry expert forecasts

Figures from NREL

- Over 68,000 MW of fixed bottom offshore wind is operating but only 213 MW floating.
- World-wide commercial expansion of floating wind expected to begin about 2026.
- Over 14,133-MW of announced projects by 2029.
- Industry forecasts predict lower deployment – about 10 GW by 2030.
- Full-scale commercial development is necessary to drive costs down.

Cost Breakdown of a Floating Offshore Wind System

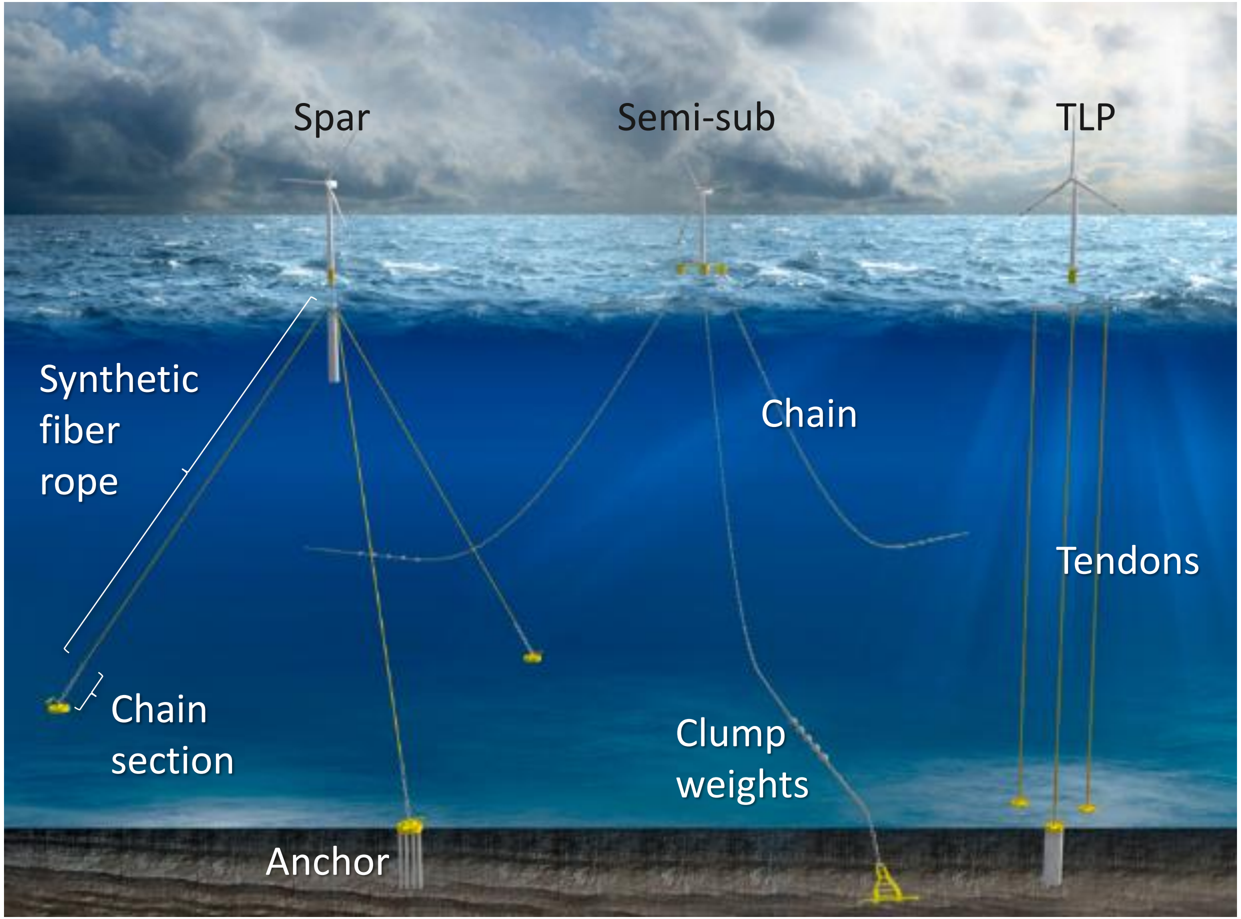


Floating Offshore Wind Capital Cost Breakdown

- The turbine cost is about 23.3% of total capital cost.
- 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

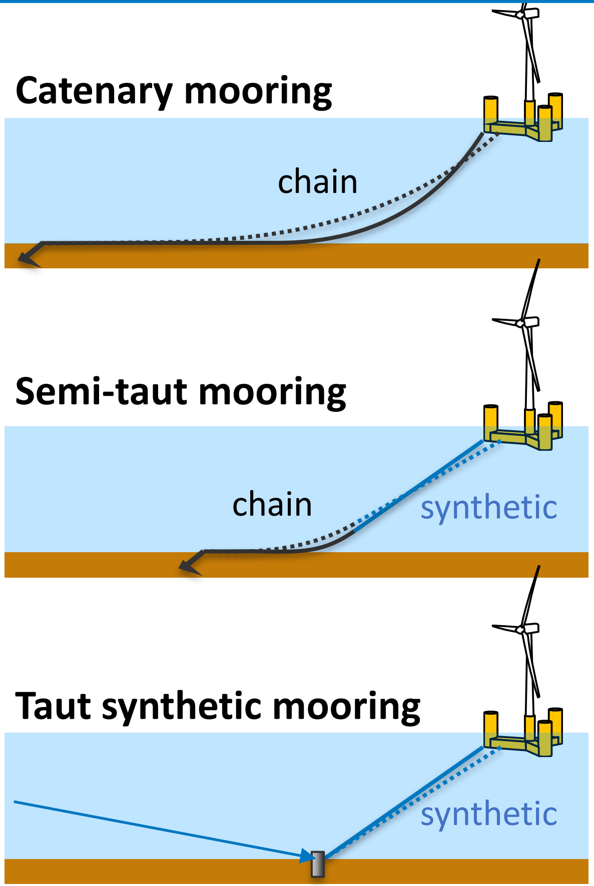


Adapting Mooring Systems for Co-existence with Fishing

Reducing Anchor Footprints

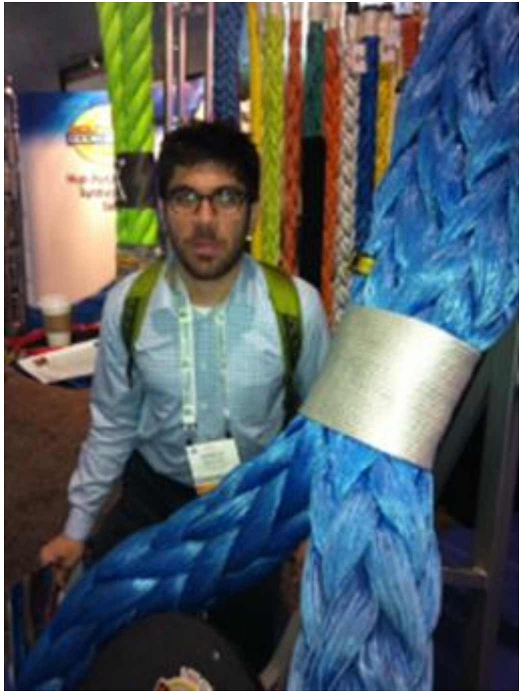
Line on seabed allows drag embedment anchors

Uplift at anchor requires suction piles or similar

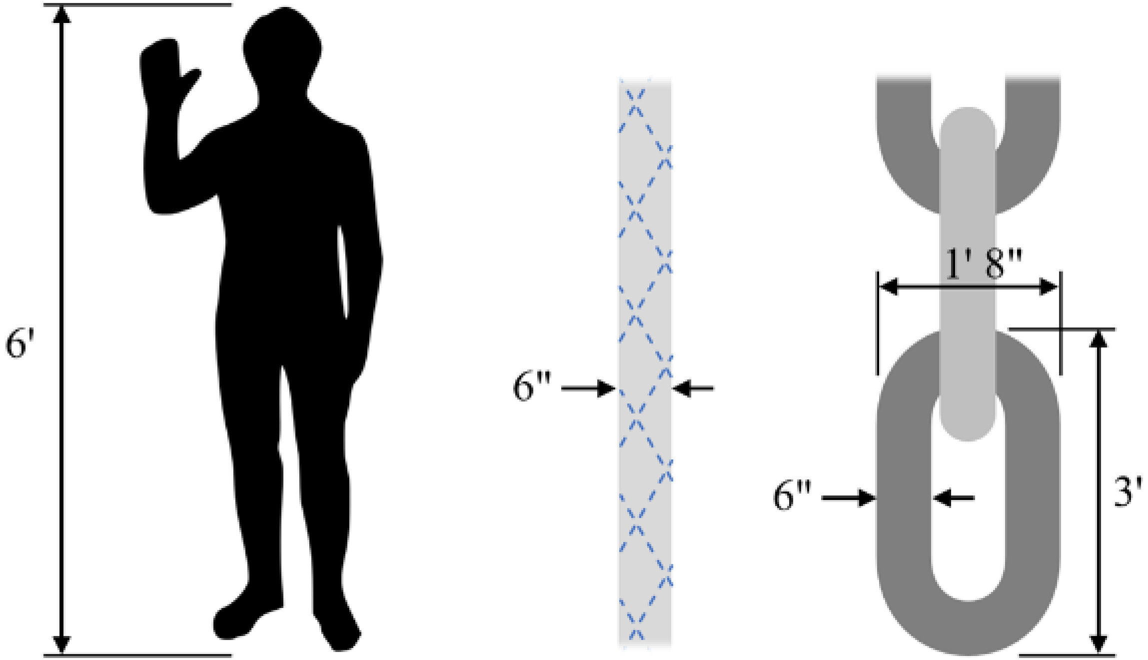


- **Catenary moorings** have the largest footprint but are the simplest.
- **Semi-taut moorings** significantly reduce the anchor distance from the turbine without changing anchor types or substructure design.
- **Taut moorings** reduce the anchor circle by more than 50% but require vertical load anchors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

Mooring Lines Materials are Heavy and Thick



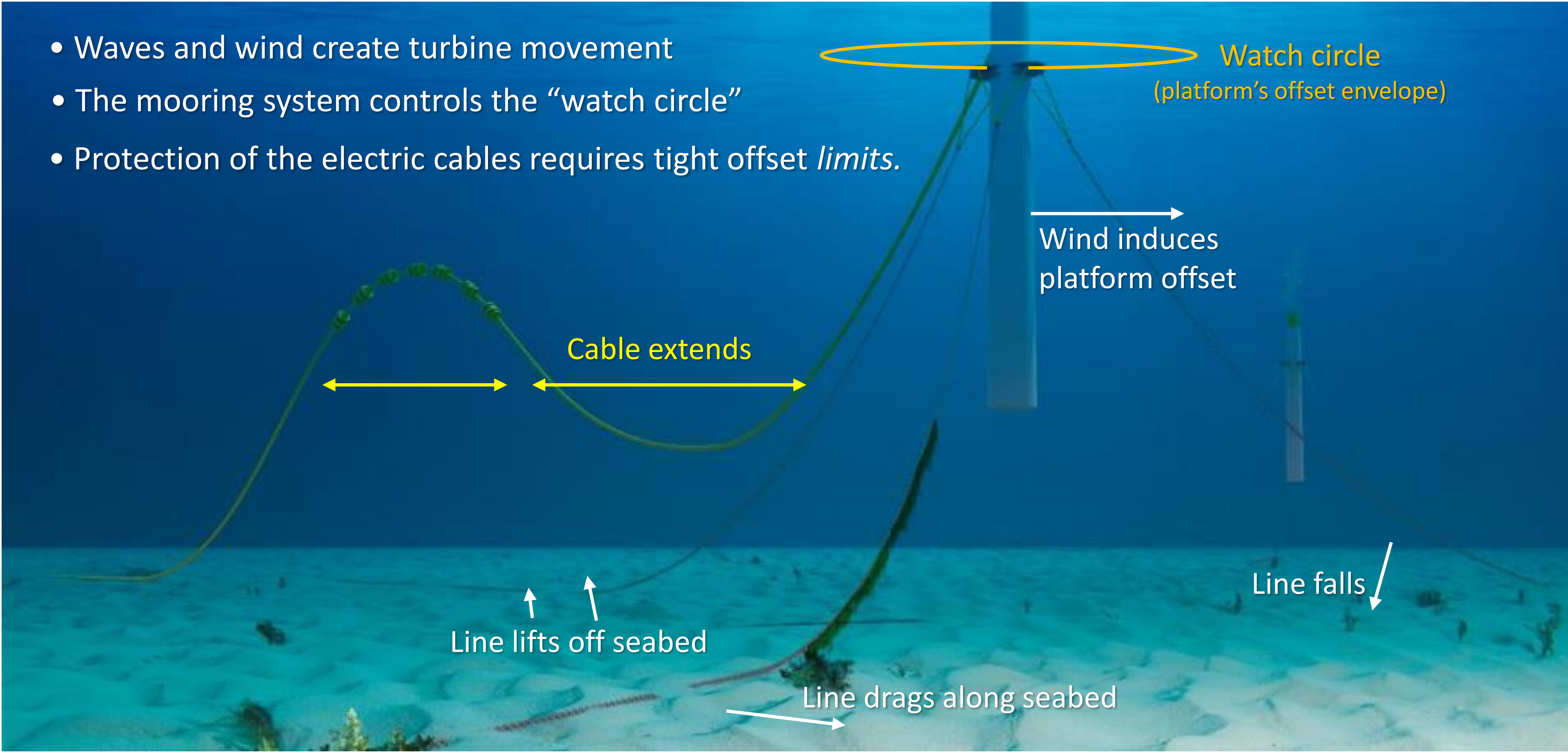
Rope Materials – Polyester, Nylon, Polypropylene. (Photo: Walt Musial)



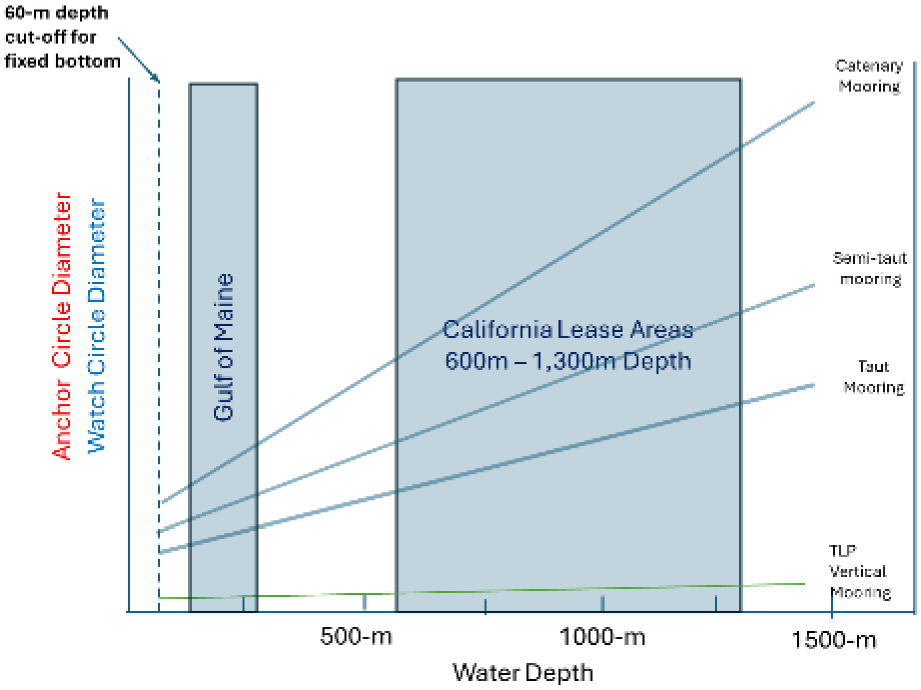
Comparison of the size of a person (left) next to representative sections of mooring rope (middle) and a mooring chain link (right). Image by Matt Hall, NREL

The Underwater View

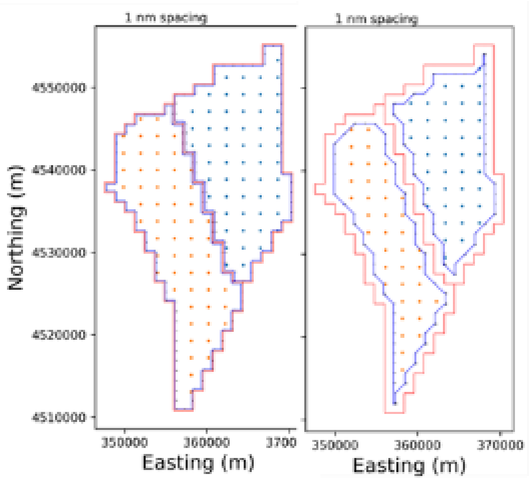
- Waves and wind create turbine movement
- The mooring system controls the “watch circle”
- Protection of the electric cables requires tight offset *limits.*



Water Depth Considerations



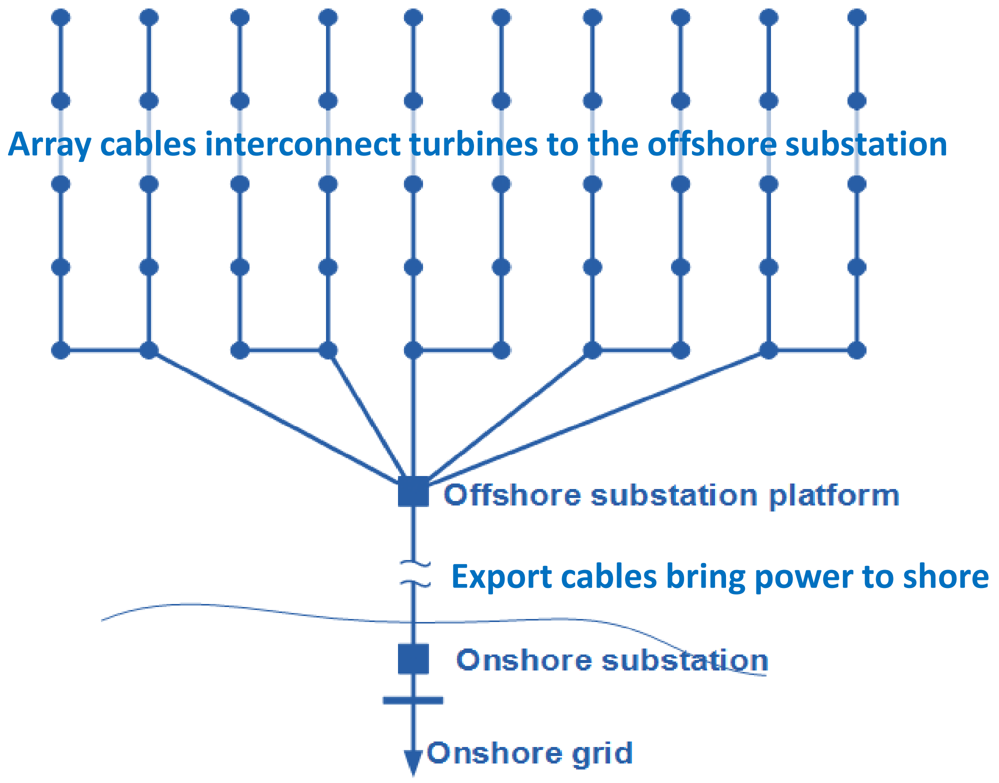
28% Reduction in Usable Lease Area between Catenary and TLP



Humboldt lease areas in northern California. (a) 1 nm spacing and TLP technology, (b) 1 nm spacing and catenary technology. The red outer lines are the lease area boundaries, and the blue inner lines indicate the mooring setback.

- Mooring type affects the usable space between turbines and the total energy capacity of the lease area.
- As water depth increases the watch circle and anchor spacing also increase.
- The shallower water in the Gulf of Maine reduces the space taken up by moorings but mooring type can still influence the available space significantly.
- Technology readiness and risk are key considerations for emerging mooring types.

Typical Array and Export Cable Layout



- Electrical array cable cost increases with turbine spacing but decreases with wind turbine size (fewer cables needed)
- Exact turbine spacing is largely a trade-off between wake losses and array cable costs
- Navigational concerns and array cable voltage also influence turbine spacing

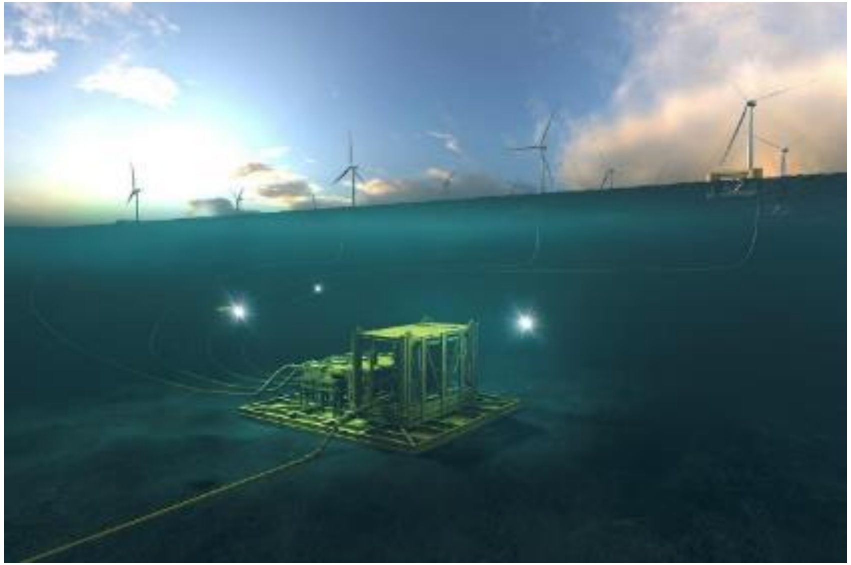
Floating Offshore Wind Substations

- Offshore substations or electric service platforms collect AC power from turbines 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.
- In the Gulf of Maine, a floating substation may be needed, but fixed bottom support structures also may be possible.
- Floating substations at full-scale have not yet been proven but many are under development. Bottom mounted substations are also under development.
- Export cable distances greater than about 50 miles will use high voltage direct current systems (HVDC) to reduce losses and cost.

Vineyard Wind 1 Substation
Photo Courtesy of Vineyard Wind

Deepwater Substations – Floating or Bottom Mounted

Semco Maritime, ISC Consulting Engineers, Aalborg University, Energy Cluster Denmark and Norwegian-Swedish Inocean have Collaboration for a Floating Offshore SubStation (FOSS).

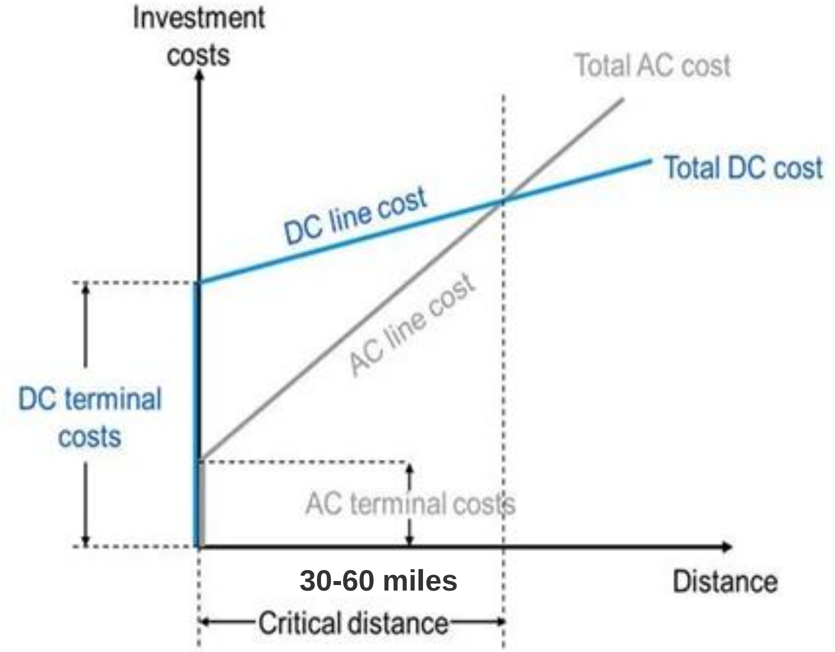


Concept for Bottom Mounted Substation by Aker Solutions

2-GW High Voltage Direct Current Converter Station

Concept of HVDC Converter Station Capable of Carrying Equivalent Energy for 1.2 million Maine Households

"TenneT will build at least 14 high-voltage direct current (HVDC) offshore grid connection systems with a transmission capacity of 2 gigawatt (GW) each in the Dutch and German North Sea by 2031".

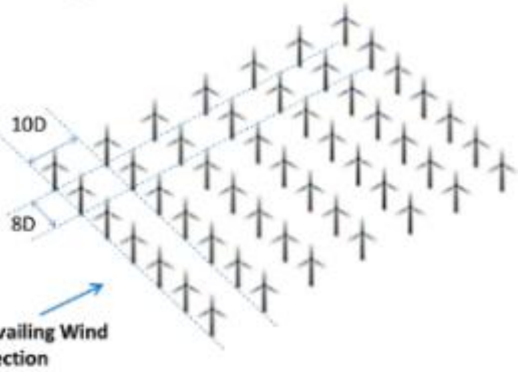


The breakeven distance where HVDC transmission becomes more cost effective is thought to be 30-60 miles – Gulf of Maine will like use HVDC systems.

https://medium.com/predict/future-of-electricity-transmission-is-hvdc-9800a545cd18

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.

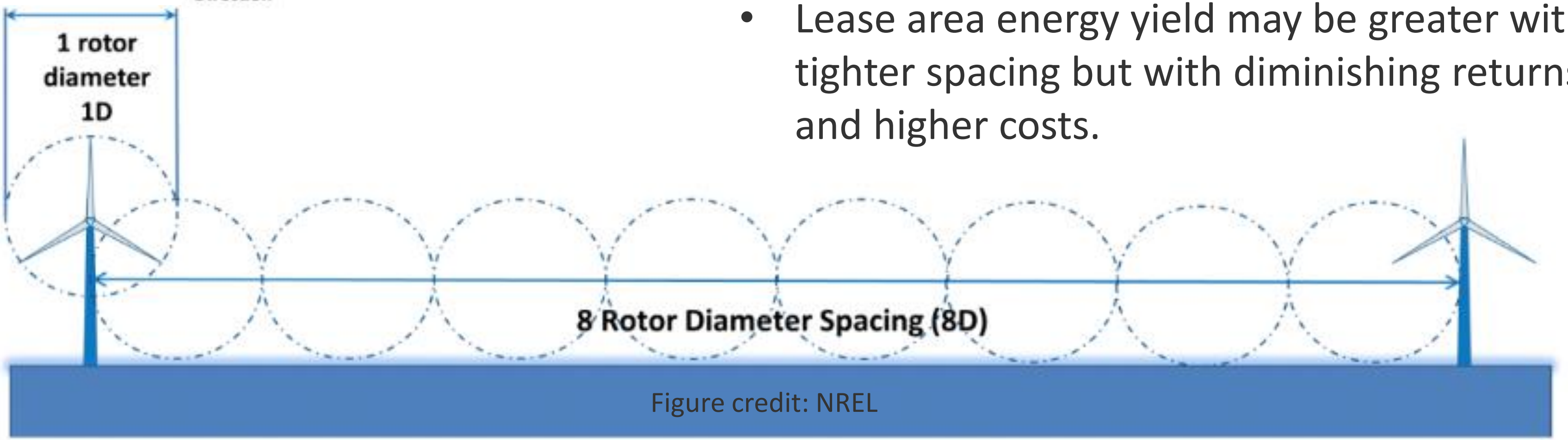


Figure credit: NREL

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

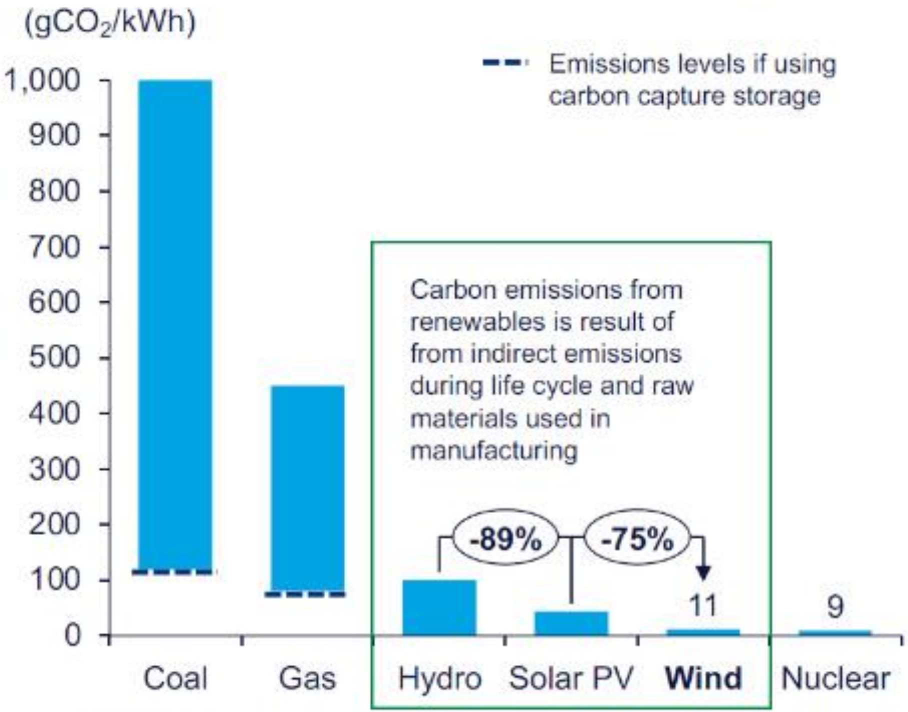
Crew Access & Maintenance

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

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 globally at utility-scale by 2027.
- Mooring systems with smaller anchor footprints are under development to maximize co-existence with fishing.
- Floating or bottom mounted substations will likely be used in the Gulf of Maine. HVDC transmission may also be more economical.
- 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