Floating Offshore Wind 101 Webinar Q & A

This Q&A document is based on the webinar, Floating Offshore Wind Overview.

Cost and Economics

Questions	Answers
Can you comment on the recent report that characterizes offshore wind in the United States as too expensive? Is the industry positioned to counter that assertion?	We are unaware of the report being referenced, but we can say recent cost declines in Europe have been verified by NREL's analysis of the revenue generated from negotiated power purchase agreements for the first few U.S. offshore wind projects suggest offshore wind: 1. Is no more expensive in the United States than in Europe 2. May soon be competitive in many electric markets, especially in the Northeast 3. May be able to provide additional benefits to the utility system, especially in constrained energy markets.
What are the most likely financing schemes for U.S. utility-scale projects starting construction in the mid-2020s or later without the benefit of federal tax credits? Is a single-owner power purchase agreement the most likely financing mechanism, absent the past tax benefits for flip structures?	For early commercial-scale floating wind projects (e.g., those in the mid-2020s), we expect project financing arrangements that are similar to today's financing of fixed-bottom wind projects in the United States. The benefits of the fading tax credits will have to be compensated through other means to make projects bankable. These other means include lower costs or technology-specific, state-mandated power purchase agreements or offshore wind renewable energy certificates, which are known as ORECs, and they may need to be used in combination with public financing. Green Giraffe has recently summarized considerations for floating wind financing in a presentation that could be helpful: Weber, Clément. 2019. *Financing Floating Offshore Wind Projects: Floating Offshore Wind Seminar*. June 6, 2019. https://green-giraffe.eu/sites/green-giraffe.eu/files/190611_2019_green_giraffe_fow_seminar.pdf.
What is the projected cost per kilowatt hour (kWh) to users?	The answer depends on the project specifics, including the location and the expected commercial operation date. In terms of levelized cost of energy, or LCOE, we estimate $5,355/kW (capital expenditures, or CapEx), $137/kW-year (operating expenditures, or OpEx), and $132 per megawatt-hours (MWh) for a commercial-scale floating offshore wind farm at a "typical" site along the Pacific Coast. See Stehly, Tyler, and Philipp Beiter. 2020. *2018 Cost of Wind Energy Review*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-74598.https://www.nrel.gov/docs/fy20osti/74598.pdf. And we estimate that by a commercial operation date of 2030, the LCOE will decline to approximately $60 MWh–$80/MWh, which is 6–8 ¢/kWh. See Musial, Walter, Philipp Beiter, Jake Nunemaker, Donna Heimiller, Josh Ahmann, and Jason Busch. 2019. *Oregon Offshore Wind Site Feasibility and Cost Study*. NREL/TP-5000-74597. https://www.nrel.gov/docs/fy20osti/74597.pdf
Does the pricing (and pricing drops) include the U.S. regulatory requirements for constructing offshore wind farm arrays?	Yes. The economic analysis accounts for the regulatory timelines and requirements. Of course, the analysis involves much speculation because no project has been built yet in federal waters.

Is the adjustable strike price the total price of the project? What is the capacity factor of these projects?	The adjusted strike price is the price the developer has negotiated to sell the electricity of the project for the life cycle of the project. Capacity factors for offshore wind projects have ranged from 40% to 55%. The Equinor 30-MW floating project in Scotland has reported capacity factors over 50%.
Is floating technology generally more expensive to construct and operate than nonfloating technology?	Currently, floating technology is more expensive, but we believe the higher costs are mostly due to the nascent stage of the technology development rather than an inherent cost premium that must be incurred. As floating technology matures, costs will fall to the range of fixed-bottom offshore wind systems.
What influences total project size for a utility-scale project—is it the size of the lease? Is it more cost-effective to build an 800-MW or a 400-MW project?	Larger projects are more economical. This is because while the apparatus and supply chain logistics for a larger project are approximately the same as those for a smaller project, more megawatts of capacity can be installed. So, an 800-MW project would generally be more cost-effective.
Why are fixed-bottom turbines not built more than 60 meters deep? Are structurally unsound in deeper water? Or, is it too expensive in terms of the amount of steel needed to install a structure at greater depths?	The oil and gas industry has installed fixed-bottom substructures at depths much greater than 60 meters. So, fixed-bottom support structures are quite feasible from a structural standpoint, but they would likely be jacket-type substructures. The assumption of a 60-meter depth transition to floating substructures is based on economics. This assumption has not been fully proven yet in transitional depths (i.e., 60–90 meters), but most floating designs are intended to go much deeper regardless of the transition depth between fixed-bottom and floating technologies.
Can the cost per kilowatt-hour quoted be broken down? How much of the initial costs will users bear and how much of it will developers pay? What about other sources such as grants and incentives?	The developer finances the costs of an offshore wind plant and recovers those costs from revenue obtained both by selling electricity generated by the turbines and by other policy incentives provided at the state level. The capital cost per kilowatt-hour is roughly broken down among turbine costs (20%); balance of system costs, including soft costs (50%); and operation and maintenance costs (30%). For more information, see Stehly, Tyler, and Philipp Beiter. 2020. *2018 Cost of Wind Energy Review*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-74598. https://www.nrel.gov/docs/fy20osti/74598.pdf
How much do greater transmission distances factor into higher costs for floating offshore wind technology?	Longer transmission in the water has a cost impact, but it is incremental and based on the length of the export cables. Once the project connects to land, there may be additional costs to bring the power to load and these costs will vary depending on the grid connection point.
When the presenter says, floating technology is "superior" at depths greater than 60 meters is that based on only economic criteria or on other criteria as well?	It's based on economics. A fixed-bottom turbine will get very expensive in deeper water because of the nonlinear power law scaling of support structure costs with water depth. In contrast, floating systems cost is relatively insensitive to water depth.
Assuming offshore wind farm arrays will displace current economic activity, is such displacement being considered?	Several recent economic impact studies estimate significant jobs and economic activity from offshore wind's component supply chain, installation, and operation activities. These studies focus on the gross economic impacts supported by wind plant development—but not net impacts to the entire economy. Further research will address other potential economic effects on areas, such as tourism, fishing, and other maritime industries. Sustaining all aspects of the blue economy is important as the offshore wind

	industry develops and some of the new offshore wind jobs require similar skills as the traditional economy.
We have seen some pilot projects in Scotland, Norway, France, Spain, and the United States with floating wind turbines. Where do you consider the boost of the technology commercially will arise?	Predicting where the first commercial project will be is very difficult, but as you mention, large-scale commercial activity is occurring in Europe and the United States, and in Asia as well.

Environmental, Siting and Marine Wildlife

Questions	Answers
How will impacts to Endangered Species Act (ESA) listed species be addressed?	Impacts to endangered and threatened species will be addressed through both ESA Section 7 “consultations” and the Marine Mammal Protection Act (MMPA) “incidental take authorizations.” ESA Section 7 requires federal agencies to ensure actions they authorize, fund, or carry out do not jeopardize the existence of species listed under the ESA. The MMPA requires that an “incidental take authorization” be obtained for the unintentional “take” of marine mammals incidental. Protection of ESA-listed marine species falls under the jurisdiction of the National Oceanic and Atmospheric Administration (NOAA). See “Endangered Species Conservation,” https://www.fisheries.noaa.gov/topic/endangered-species-conservation. NOAA also is charged with the protection of marine mammals under the MMPA. See “Marine Mammal Protection,” https://www.fisheries.noaa.gov/topic/marine-mammal-protection.
Do mooring lines or cables suffer from biofouling? If so, what are the maintenance actions and frequency to maintain the integrity of the lines/cables?	We have little data on biofouling because of a lack of experience overall, but the industry anticipates biofouling—the growth of organic plants and animals on submerged structures—will represent a routine maintenance issue. Several methods for inspection and mitigation, including robotic techniques have been proposed. And better information will become available when more industry experience is acquired.
Are there differences between what environmental impact assessments require for anchored and floating wind projects, particularly in relation to marine life?	Environmental impact assessment requirements for federal waters fall under the authority of the Bureau of Ocean Energy Management. See their “Survey Guidelines For Renewable Energy Development,” https://www.boem.gov/renewable-energy/survey-guidelines-renewable-energy-development. Currently, posted guidelines are agnostic about foundation type and impacts.
What are some environmental challenges associated with floating offshore wind turbines? Do any challenges overlap with those of fixed-bottom technology?	At a high level, the environmental challenges of fixed and floating systems overlap considerably. However, the context changes considerably depending on the benthic habitat, species composition, and biomass on the continental shelf versus the continental slope, where water is much deeper. Different ecosystems are expected to respond differently to different stressors. Furthermore, the disturbance during construction and the installed infrastructure among substructure types also vary. Although seabirds and bats both fly offshore, they do not use the same space. So, as with changing context under the surface, we may also see different species composition above the surface based on the distance from shore.

Can hybrid floating wind turbines operate in water shallower than 60 meters? There is growing interest in “quiet” foundations that don’t require pile driving, which can significantly impact marine wildlife.	It is possible to design a floating wind turbine that can operate in less than 60 m of water, but there are challenges with short mooring lines in shallow water.
Do cables mooring the turbines affect whales?	Mooring lines that secure floating platforms to the seabed extend through the entire water column. They are very large in diameter and are made from chain or synthetic rope. Unlike fishing lines or smaller diameter rope lines, they experience large axial forces. So, it would be very difficult for marine life to become entangled in the lines. Where concern remains is around secondary entanglement where marine debris (such as fishing gear) may become entangled in the line which may pose an entanglement risk to wildlife. However, this is a topic that deserves further research to better understand the likelihood and magnitude of risk.
How do marine mammals deal with fixed and floating platforms? Do they all use sonar to maneuver around the underwater portions of these structures?	Different marine species use different strategies to navigate their environment. They would use these same strategies to maneuver around underwater obstructions.
Structures further offshore may also have more impacts on marine wildlife. How should this be considered when selecting sites?	When evaluating site options, one should consider the differences in benthic habitat and species composition for each site. However, there is currently a paucity of information to support an assessment of the relative impacts to marine ecosystems on the continental shelf and the continental slope.
Did the proof-of-concept and pre-commercial projects include data collection on observed impacts to the marine environment and wildlife? How do floating and fixed platforms differ in in terms of these types of impacts?	We believe the early projects in Europe and Japan did consider impacts to wildlife, but data are not always publicly available. Insufficient research has compared impacts for floating and other substructure types. And the benthic habitat and species composition at a given site may be more or less sensitive to a particular substructure and the associated construction activities. Future research will need to consider such impacts.
Do floating wind projects measure impacts—or calculate cumulative impacts—on either marine mammals such as sea turtles or birds and bats? And is it necessary to activate any adaptive management practices?	Floating wind projects will be required to comply with the same requirements for preconstruction and post construction monitoring as other offshore wind energy projects. Practically, to monitor offshore activities, technologies and components must withstand the harsh marine environment and operate reliably in remote locations. The U.S. Department of Energy is investing in research and development to augment the suite of options available for robust and practical monitoring regimes. Such technological solutions will support data collection to assess the source and magnitude of impacts for a given project, and the resulting data may inform adaptive management practices or cumulative impact assessments. For an introduction to some of these research projects, see “New Research on Wildlife Monitoring at Offshore Wind Energy Facilities Supported by the U.S. Department of Energy,” National Wind Coordinating Collaborative, https://www.nationalwind.org/new-research-on-wildlife-monitoring-at-offshore-wind-facilities-supported-by-the-u-s-department-of-energy/.
Can you describe testing that has been done to determine the potential impacts to birds from potential blade strikes and to cetaceans from potential collisions with underwater cables or other subsurface structures associated with offshore wind farm arrays?	While collisions are a concern for volant species offshore, studies to date suggest impacts from avoidance is also of concern. BOEM Pacific summarized the state of the knowledge well in a recent webinar (Pereksta, David M. 2020. *Birds and Offshore Wind Energy Development: BOEM's Avian Study Strategy to Assess Data Needs and Effects*. BOEM Pacific OCS Region. January 8, 2020.

	https://www.boem.gov/sites/default/files/documents//West-Coast-Science-Exchange-20200108.pdf).
Does floating offshore wind technology have a smaller impact on benthic habitats?	When evaluating site options, one should consider the differences in benthic habitat and species composition for each site. However, there the currently paucity of information does not support an assessment of relative impacts to marine ecosystems on the continental shelf and the continental slope.
What effects do floating offshore wind projects have on seabirds?	Impacts to seabirds from offshore wind include collision and avoidance. A recent webinar from BOEM Pacific provides a detailed summary of the state of the knowledge (Pereksta, David M. 2020. *Birds and Offshore Wind Energy Development: BOEM's Avian Study Strategy to Assess Data Needs and Effects*. BOEM Pacific OCS Region. January 8, 2020. https://www.boem.gov/sites/default/files/documents/West-Coast-Science-Exchange-20200108.pdf).
Are there entanglement risks associated with floating wind turbines for whales or other marine mammals?	Entanglement with mooring lines is not expected to be a problem for whales because the lines are big, heavy, and tight. However, secondary entanglement my present a concern if marine debris that becomes entangled in lines poses an entanglement risk to wildlife. And this topic deserves further research to better understand the likelihood and magnitude of risk.
Unlike fixed-bottom turbines—whose cables are buried in the seafloor—floating offshore cables are in the water column. Has the industry addressed possible transit conflicts between the floating cables and users, such as the Department of Defense or the shipping and fishing industries?	We do not anticipate that floating turbines will significantly impact transit, as they will be more than one mile apart and the cables will be much deeper than the drafts of surface vessels. Of course, conflicts becomes more of a concern when visibility is low. However, techniques and technologies such as lighting may be implemented to provide additional navigational safety. Fishing activities that involve bottom trawling would likely be impacted within a wind array.
Do you have any insights about floating wind technology and marine spatial planning—in particular, the mooring and cabling infrastructure and its impacts on training waters used by the U.S. Navy?	There have been many serious discussions about this subject, but the discussions are not always in the public domain. Competing uses will need to be carefully considered. We cannot speak to the needs or concerns of the Department of Defense; however, we can say that spacing between turbines will typically be over one mile and the mooring lines and cables would be much deeper than the drafts of any surface vessels.
Fishing	
Are floating offshore wind turbines less challenging for commercial fishermen and other commercial vessels to navigate around than fixed-bottom turbine farms of the same size?	In terms of commercial navigation, floating wind turbines and fixed-bottom turbines are about the same.
Fixed-turbine project managers work closely with fishermen so that both can use ocean resources. With the tethering cables, it seems all commercial fishing would be displaced. What is the protocol for commercial fishing around floating turbines?	Mooring lines would be a significant challenge for large-scale commercial fishing inside a floating wind farm, but it is premature to assume all commercial fishing would be excluded. This issue has not yet been fully addressed, but it should be a topic for further research and discussion.
With spacing of eight-rotor diameters, would smaller vessels (say commercial fishermen) be able to safely navigate an array?	Eight-diameter spacing will set the turbine spacing at one mile or more. This distance would allow safe passage for most smaller vessels.

Fisheries have led to increased spacing for fixed-bottom turbines in the Northeast. Has there been any feedback on either spacing for floating turbines or sub-surface mooring configurations?	Because of the nascent state of the industry, this issue has not been addressed yet.
What is the expected offset of fishery jobs with the development of floating wind technology?	There is no evidence offshore wind plants hurt fish populations, and many believe that they can be beneficial to fish by providing artificial reefs and feeding grounds The offshore wind industry is working closely with the fishing industry to minimize the economic impact on the fishing industry. The large-scale deployment of offshore wind would occupy a small fraction of the ocean, so fishing would continue normally in most ocean areas. Nevertheless, there is much discussion about how fishing could continue within the wind plant farms as well. Ideally, the fishing community and the wind industry would work together to create more jobs. For more information, contact the Responsible Offshore Development Alliance (RODA, hrodafisheries.org).
At what depth will inter-array cables be mid-water instead of the bottom? The mid-water cables essentially exclude all fishing activity inside the array.	The depth of the array cables and the method of placement within the array are all variables of the floating array design. The degree to which fishing activity is disrupted depends on the type of fishing under investigation. The offshore wind industry would seek to minimize fishing impacts, and some project-specific impacts might need to be mitigated by the developer.
What are the opportunity and economic costs to commercial and recreational fishermen, and how are they mitigated?	Competing use issues—of which there are many—were not in the scope of this webinar because of time constraints. These issues deserve a lot of attention and should be the subject of future webinars. For more information, contact the Responsible Offshore Development Alliance (rodafisheries.org).

Configuration, Design, Sizing & Installation

Questions	Answers
Why do wind turbines have only three blades?	Over the years, wind turbines have been designed with different numbers of blades, but experience has shown three-bladed rotors to be the optimal design for energy capture. Increasing the number of blades not only increases the design complexity and cost; it does not improve the energy yield. Two-bladed rotors can also work, but they are dynamically more challenging.
Is anyone pursuing turbine technology other than three-blade upwind technology? Also, does the size of the underwater structure vary with the size, weight, and rotor diameter of the turbine?	A few researchers might be looking at two bladed turbines. Some may also be pursuing vertical-axis machines. The size and weight of the components above the water directly affect the size and weight of the underwater structure.
Are helical turbines an option offshore for either fixed or floating technology?	Not currently. Helical turbines exist at smaller scales and have been demonstrated for marine current applications. However, they have not been demonstrated at the megawatt-scale for commercial- or utility-scale wind, as they are very difficult to scale up to utility-scale without incurring large weight (and hence cost) penalties; also, they are less efficient at capturing wind energy.

Can you verify that the technology filter on Slide 11 for a water depth of less than 1,000 feet is correct?	The technology filter for the resource was to eliminate all area with depths greater than 1,000 *meters*—not feet.
What will the entire footprint of an offshore wind facility be, including the mooring apparatus?	The facility footprint depends on water depth, mooring type, and mooring design. Catenary moorings have a footprint (measured by the anchor circle radius) that is proportional to the water depth. The mooring lines are at least four times longer than the water depth. In a tension leg platform, the mooring lines are taut and relatively vertical, so the footprint is much smaller.
In the catenary mooring line figure (Slide 20), what is the anchor radius as a factor of water depth? Does this measure impact turbine spacing?	The figure is conceptual and is not intended to represent a specific design, but the anchor radius is at least as great as water depth but likely greater. This dimension is generally independent of turbine spacing, but new concepts for shared moorings and shared anchors may influence future mooring system designs to also consider turbine spacing.
Can you provide information about the mooring scope required for the different types of platforms (based on water depth)?	Spar and semisubmersible substructure platforms typically use catenary moorings, which sag along their length such that the anchor line forces are mostly horizontal. Tension leg platforms, or TLPs, have vertical mooring line forces that are an order-of-magnitude larger; they therefore do not use drag embedment anchors but instead use pile type anchors that can take large upward forces.
How many anchor lines are used?	A minimum of three mooring lines is required to stabilize the floating substructure. Design standards for oil and gas require some redundancy in the design, so this number may be doubled. The exact requirements are still being debated under U.S. and international standards development committees.
Are anchor lines under tension? If so, how much tension?	Yes. The anchor lines are under tension, and these tensile forces provide stability to the system. In catenary mooring systems, the tension is created by the weight of the mooring lines themselves, which are typically made of heavy steel chain.
How are the anchors embedded/installed? (Slide 19)	The drag embedment anchors are installed using vessels that pull on them from the surface. They are designed to penetrate the seabed as they are dragged along the bottom; the harder an anchor is pulled, the deeper it penetrates.
At what depth will inter-array cables be mid-water instead of at the bottom? These mid-water cables essentially exclude all fishing activity inside the array.	The depth of the array cables and the method of placement within the array are all variables of the floating array design. The degree to which fishing activity is disrupted depends on the type of fishing. The offshore wind industry would seek to minimize fishing impacts, but some project-specific impacts might need to be mitigated by the developer.
At what range of depths can floating offshore wind turbines be installed? Is there any expectation that floating technology will be used in water depths less than 60 meters?	The expected water depth range is 60–1,000 meters. Shallow water floating systems below 60 meters could be possible, but fixed-bottom substructures become more competitive as depths decrease. Also, shallow water moorings with their shorter lines pose additional technical challenges.

When developing larger turbines, what is the limiting factor? Or, on what basis do you decide whether the turbine size is even applicable?	Larger turbines mean fewer turbines are needed per project. And fewer turbines mean fewer array cables and connections, lower maintenance, more energy (because the towers are taller), fewer support structures, et cetera. When upscaling turbines, two significant challenges are maintaining first, high reliability composite blades that are longer and carry more load, and second, drivetrains that operate at increasingly slower shaft speeds. But maybe most important is the port and supply chain infrastructure that manufactures, assembles, installs, and maintains the largest structures, which can be mammoth.
Is there a turbine size limitation for floating offshore wind in terms of the amount of mass required to offset the turbine weight?	In most cases, mass must be added below the waterline as ballast to offset the weight of the turbine and more importantly the horizontal thrust loads due to the wind. The mass below the water line is generally not a large cost penalty because it is typically obtained using no-cost or low-cost materials such as seawater, concrete, or iron ore.
Are you aware of key areas that might be ripe for work in academia, such as mooring systems, environmental impacts, or other topics?	Offshore wind is a rapidly growing field, and training the engineers, technicians, biologists, scientists of the future is a high priority for the industry. Key fields of possible study include resource assessment and characterization, wind plant control and optimization, wind technology innovation and modeling, advanced manufacturing and materials, grid systems integration and hybrid systems development with complementary technologies such as solar, testing and validation, techno-economic analysis, marine environmental science and regulatory policy, and stakeholder relations.
Do you expect installations will need to be compliant with the Jones Act?	Yes. Any structure installed in U.S. waters is considered a U.S. port and would need to be Jones Act compliant. That means the vessels that install the structure and deliver its various components would have to be compliant. Generally, this mean U.S.-flagged vessels will be used if parts are transferred from a U.S. port to the operating site.
Is floating wind technology "settled" for the floating parts, or are different float designs still competing for dominance?	The technology is still evolving. Several technology types may move forward because physical and environmental site requirements may dictate different design optima. To optimize for regional differences, lower costs will also drive the technology in various directions.
Has there been offshore wind development in the Hawaiian Islands?	No, there are not any offshore wind farms in Hawai'i.
What does AWH stand for in the U.S. Regulatory Activity slide?	AWH stands for Alpha Wind Hawai'i.
Has a port study of the United States been conducted to show which ports could potentially stage floating turbine quayside construction?	Mott MacDonald conducted a port study for BOEM in 2016 that provides some good information. See Porter, Aaron and Shane Phillips. 2016. *Determining the Infrastructure Needs to Support Offshore Floating Wind and Marine Hydrokinetic Facilities on the Pacific West Coast and Hawaii*. Portland, OR: ICF International. BOEM 2016-011. https://www.boem.gov/sites/default/files/environmental-stewardship/Environmental-Studies/Pacific-Region/Studies/BOEM-2016-011.pdf
Electrical and Transmission	

Questions	Answers
Sites farther offshore may be better for people (i.e., out of sight) but will still need infrastructure to transmit electricity to shore. What will be needed to do that? Will bringing electricity to shore be more difficult for locations farther offshore?	The farther offshore the project is built the longer the export cable needs to be, which does add some cost. In the North Sea, offshore wind projects have economically built more than 60 miles offshore. If the project is very far from shore new technology such as high-voltage DC current is being used to help reduce transmission losses and save costs. Although these distances may seem large, they are smaller than some land-based transmission distances.
Do wind turbines require any electrical energy during start-up?	The electric grid to which the wind plant is connected must be energized to start. All components of wind power plants (such as substation transformers, collector system cables, turbine transformers), including all turbine-level components (such as all auxiliary circuits, controls and actuators, and yaw system) must be energized using power from the grid so that each individual wind turbine in the plant can start operating. Once a turbine starts spinning under wind flow, it still needs energy to control some if its components (such as blade pitch motors) to regulate turbine speed and allow the turbine converter to synchronize with the grid. Only after that is the turbine's main contactor engaged and can the turbine start producing power. A turbine's internal consumption is normally much lower than— less than 1%–2% of—the rated power of the unit. Also, "black start" capabilities are under development in which wind plants can energize the grid in the event of a blackout.
What amount of electrical demand might make floating wind practical? I'm particularly interested in Hawaii, where a 400–500 MW project would be a major portion of the load on the island of Oahu.	A study done at NREL indicate that an 800-MW offshore plant off Oahu would provide about 40% of the island's electricity. Because Oahu makes up about 80% of Hawaii's electric load, it does not seem practical to consider offshore wind for other Hawaiian Islands at this time. For reference, Hawaiian Electric, or HECO, generated about 6,782 gigawatt-hours (GWh) per year in the year the study was done.
Have you done a "crosswalk" of those areas where floating technology would be best and the onshore transmission system could handle the power? I know from other presentations I've seen that considerable onshore upgrades will be required, and no one is sure who will pay for these upgrades.	As land-based power plants such as the Brayton Point Power Station in Massachusetts retire, the East Coast has considerable opportunities for offshore wind projects to connect to existing coastal infrastructure with minimal additional land-based upgrades. However, with more than 26 GW of offshore wind committed in the United States, we can expect a future shortage of easy-access grid connection points and additional costs will be incurred to make the needed transmission upgrades. As you stated, it is unclear who will pay for these upgrades, but states, developers, and utilities are already having these discussions. In California, where floating wind may be deployed, there are significant grid connection challenges, especially on the North Coast. Solutions to these challenges may require a large (gigawatt-scale) offshore wind capacity addition to make projects economical regardless of who pays for them.
How much does longer transmission factor into costs for floating offshore wind?	Longer transmission in the water does have a cost impact, but it is incremental and based on the length of the export cables. Once a project connects to land, any additional costs to bring the power to load will vary depending on the viability of the grid connection point.

Do the power cables that draw energy from floating wind turbines float as well?	No. They are heavy and sink to the seafloor. They are connected to the turbines and protected from the dynamic motions of the turbine.

Modeling, Analysis, Controls and Resource Assessment

Questions	Answers
What type of modeling is used for each type of mooring system (spar, floating, and tension line) to evaluate its tolerance to oceanic forces over time and a range of ocean conditions and storm events? Is modeling required for each individual project, or can a standardized model with specified ocean conditions and a predetermined error range be used?	Floating wind turbine systems are designed by considering the entire wind turbine, platform, and mooring assembly together in what is called a fully coupled dynamic analysis. Such an analysis accounts for thousands of possible load cases to calculate the full system responses. To obtain type certification and project certification, which are necessary for regulatory approval and financing, each design and each project must be fully evaluated. The software needed to make these computations is very specialized and models the physics of both the aerodynamic loading and the hydrodynamic loading under all foreseeable conditions as prescribed by International Electrotechnical Commission standards.
In the development of wind farms, how accurate are the data used to simulate turbine spacing?	The models you may be referring to predict the wake losses from each turbine within an array for a given spacing distance. The models' accuracy is very good, and these models are the primary tools used to determine the tradeoff between array cable length and net energy production.
Are commercially available software tools used for techno-economic analysis of offshore wind?	Not that we know of—the industry is changing so rapidly that commercializing such a tool would be difficult.
When will the data for the 15-MW NREL Reference Turbine be available?	The full report on the International Energy Agency (IEA) Wind 15-MW Reference Turbine is available in Gaertner, Evan, Jennifer Rinker, Latha Sethuraman, Frederik Zahle, Benjamin Anderson, Garrett Barter, Nikhar Abbas, et al. 2020. *Definition of the IEA 15-Megawatt Offshore Reference Wind*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-75698. https://www.nrel.gov/docs/fy20osti/75698.pdf. And the design is implemented as input files to various modeling tools, which are available on GitHub ("IEAWindTask37/IEA-15-240-RWT," https://github.com/IEAWindTask37/IEA-15-240-RWT).
Does the nature of the ground surface affect the quality of the wind resource? For example, are wind resources lower in hotter areas?	Winds tend to blow stronger in colder climates, but tropical and subtropical coastal regions have trade winds and often have strong land-sea thermal gradients that can help generate consistent winds. A site-specific resource assessment can help determine whether a site is viable for offshore wind.
Has a floating turbine ever fallen over? How would that be managed?	No. There have been no cases of a floating turbine falling over. Turbine systems are designed to withstand harsh sea conditions using advanced computer simulation codes that ostensibly eliminate this failure mode. The offshore wind design criteria are adapted from 50 years of oil and gas experience and have been continuously upgraded as these industries collectively learn more.