FLOATING FOUNDATIONS: A GAME CHANGER FOR OFFSHORE WIND POWER

A SUPPLEMENT TO *INNOVATION OUTLOOK: OFFSHORE WIND (IRENA, 2016)*

Today's offshore wind turbines, rooted to the seabed by monopile or jacket foundations, are restricted to waters less than 50 metres deep. This rules out sites with the strongest winds and, often, access to big markets. Floating foundations, by eliminating the depth constraint and easing turbine set-up, could open the way for power generation from deeper waters.

Motivation to develop floating foundations

Some of the largest potential markets, such as Japan and the United States, possess few shallow-water sites suitable for offshore wind development. **Floating foundations could be game changers in this regard.**

Floating foundations offer the offshore wind industry two decisive opportunities:

- They allow access to deep-water sites. In water deeper than 50 metres, they offer access to large areas with a strong wind resource and proximity to population centres. For some countries, such as those with a narrow continental shelf, floating foundations offer the only opportunity for large-scale offshore wind deployment.
- **They ease turbine set-up.** In mid-depth conditions (30-50 metres), they may in time offer a lower-cost alternative to fixed-bottom foundations, given the potential for standardisation of foundation designs and the use of low-cost, readily available installation vessels.

In addition, floating foundations generally offer environmental benefits compared with fixed-bottom designs due to less-invasive activity on the seabed during installation.

Current status of floating foundations

Floating foundations are already proven in harsh operating environments. The main concepts for offshore wind power are well known in the oil and gas sector, where they are deployed commercially at a large scale.

Platform designs for offshore wind, however, require adaptation to accommodate different dynamic characteristics and a distinct loading pattern. The same process has already occurred to a great extent for fixed-bottom foundations, including monopiles, jackets and gravity-base designs.

Commercialisation of floating wind farms is anticipated between 2020 and 2025. The first full-scale prototypes for floating wind turbines have been in operation for several years. Demonstration continues for new floating foundation concepts. The first floating wind farm, with 30 megawatts (MW) of power generation capacity at more than 100 metres (m) water depth, is scheduled to start operating off the coast of Scotland by the end of 2017. By 2020, based on progress seen in the market, three to five additional foundation designs should have been demonstrated at full scale (2 MW or larger).

The three main concepts for floating foundations are spar-buoy, semi-submersible and tension leg platform, as illustrated in figure 1. Variants on these also exist, including the mounting of multiple turbines onto a single floating foundation.

Table 1 describes each of the three concepts, including their pros and cons and the status of first movers, fast followers and others developing the technology.

Figure 1: Offshore wind floating foundation concepts

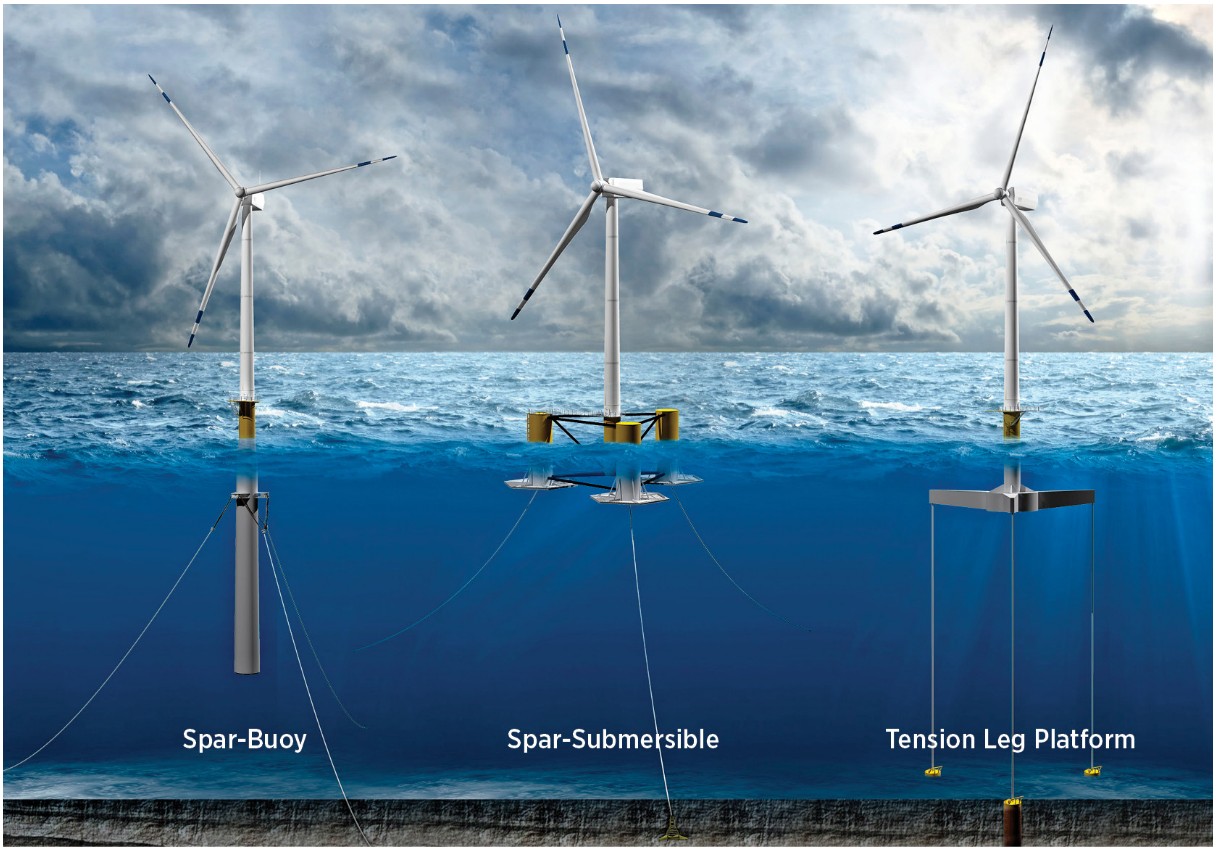

Illustration by Joshua Bauer, National Renewable Energy Laboratory (US Department of Energy)

Deployment and cost-of-energy goals

To contribute significantly to the global energy mix in the coming decades, floating offshore wind systems need to become less costly and, in turn, to be widely deployed.

If market uptake is too slow, then the supply chain will not materialise, and costs will not come down rapidly enough for floating offshore wind to keep up with cost-of-energy reductions anticipated in other technologies. As with any technology, there is strong interaction between market volume and cost.

Barriers to deployment

Commercialising and deploying new technology in the energy sector is always a big challenge. It involves a conservative business sector, requires large quantities of capital, takes considerable time and affects a broad range of stakeholders. In some cases, it requires cultural change.

While many of the technical principles of floating offshore wind have been demonstrated, barriers to large-scale deployment remain. Floating offshore wind technology, even more than its fixed-bottom counterpart, faces two major, and inter-related, challenges:

- The magnitude of the commercial challenge, in terms of being investable and finding investors;
- A mismatch between innovation "horsepower" and corporate staying power.

Being investable and finding an investor

About 20 players are already involved in moving floating foundation technologies from the early-concept stage through to commercial deployment. This maturation is likely to require another 15 years, and there are no existing markets to tap for commercial-scale floating offshore wind technologies.

For any given player, today's pre-commercial projects (single demonstrator, 5- to 10-turbine pilot, then first utility-scale project of 200 MW-plus) could require a total investment (in excess of market-rate project revenues) of hundreds of millions of dollars over the lifetime of the projects. Even the operating costs for the floating foundation technology company itself (staff and third-party costs to develop and take the technology to market) are tens of millions of dollars over a 10- to 15-year period.

The time needed to attain profitability is long, and the sums of money required are large, considering the uncertainty in the eventual market. Market potential depends on the relative advancement of offshore wind compared to other forms of electricity generation and on addressing specific technical risks related to floating offshore wind. As a result, the financial profile of a floating foundation technology company does not match the needs of most private investors.

In a few cases, private investors are bearing the technology company's operating costs and a small portion of above-market pre-commercial project costs. Similarly, the French, Japanese and Scottish governments, along with the European Commission, are stepping forward with project-support mechanisms.

At present, however, there is no clear path for the leading technologies to gain enough support to reach utility-scale commercial deployment. The fast followers that are presently preparing for demonstration projects have a possibly even greater challenge, since the first movers tend to capture and consume pre-commercial project support.

Innovation "horsepower" vs. corporate staying power

Most of the innovative floating foundation designs are being developed by small- to medium-sized businesses. Among the leading multinational corporations already active in the offshore wind sector, only a few players (including Iberdrola, Mitsubishi Heavy Industries and Statoil) have publicly announced programmes of in-house floating foundation development. The smaller, innovative companies do not have the resources to push new products all the way to market. While acquisition by larger companies is one logical solution, most innovators are unable to prove that their designs and business plans are sufficiently mature for the scale of investment needed, from any source. This has led to several stranded technologies.

Investors in the sector, however, have the potential to see good returns, even though this may occur over longer time periods than they are used to. This is because floating offshore wind has the prospect of creating a much larger global market than fixed-bottom offshore wind, due to the massive area of deep water with good wind resources. In addition, floating technology appears set for commercialisation just when offshore wind using conventional foundations reaches cost parity with other large-scale energy generation technologies.

A range of types of organisation could drive floating foundation development. (However, each also has strong logic for not leading these efforts.) The challenge is to get enough of these types of organisation collaborating together for eventual mutual benefit.

Turbine manufacturers could integrate a floating foundation into their commercial offering, but they already carry significant technical and commercial risk with their next-generation offshore wind turbines. Instead, some turbine manufacturers are agreeing to collaborate with innovators and to sell turbines into pre-commercial floating projects.

Offshore wind project developers could pursue previously uneconomic project sites by including floating foundations in their offering, but these firms already carry project development risk with their pipeline of conventional projects. Instead of taking on the development risk for projects with pre-commercial technology and contributing project equity investments, some developers are offering paid services to floating foundation technology developers.

Governments could establish low-carbon, secure energy generation by funding floating foundations. The Japanese government, for example, has taken great strides in supporting floating offshore wind. Governments, however, are often limited in their ability to support private enterprises. Instead of funding the full commercialisation of floating foundations, governments generally offer limited technology acceleration funding and financial support for pre-commercial projects.

Private equity firms could invest in game-changing technologies such as floating foundations to get long-term profit streams from such investments. These companies, however, generally require a return on investment within three to five years. To date, there have been few private equity investments in floating offshore wind, with the notable exceptions of investments in Principle Power (US) and Ideol (France).

Global energy majors could diversify their energy generation portfolio by developing floating foundation technologies and the associated wind farm projects. Many global energy majors remain unconvinced about the viability of offshore wind, however, or simply are not inclined to invest in renewables or in technology businesses with such a long route to market.

Corporate strategic investors are the private equity arms of companies whose main business would gain from the success of emerging technologies. They often require other investors to join the venture and share the risk, and require cost recovery during the pre-profit phase of development. The cost recovery requirement drives corporate strategic investors to

Leading technology types for floating offshore wind power

Description	Status
Spar buoy A cylinder with low water plane area, ballasted to keep the centre of gravity below the centre of buoyancy. The foundation is kept in position by catenary or taut spread mooring lines with drag or suction anchors. **Pros:** • Tendency for lower critical wave-induced motions • Simple design • Lower installed mooring cost **Cons:** • Offshore operations require heavy-lift vessels and currently can be done only in relatively sheltered, deep water • Needs deeper water than other concepts (>100 metres)	**First movers** **Statoil (Hywind)** • Demonstrated in Norway in 2009 (2.3 MW Hywind) and planned in Scotland in 2017 (5 x 6 MW array) Toda • Demonstrated in Japan in 2013 (2 MW hybrid spar); partners include Kyoto University, Sasebo Heavy Industries and Nippon Hume **Fast followers** **Japan Marine United** • Demonstrated in Japan in 2013 (advanced spar used to support floating substation) and in 2016 (5 MW) **Other players (examples)** • DeepWind, SeaTwirl, Windcrete
Semi-submersible (or "spar-submersible") A number of large columns linked by connecting bracings / submerged pontoons. The columns provide the hydrostatic stability, and pontoons provide additional buoyancy. The foundation is kept in position by catenary or taut spread mooring lines and drag anchors. **Pros:** • Constructed onshore or in a dry dock • Fully equipped platforms (including turbines) can float with drafts below 10 metres during transport • Transport to site using conventional tugs • Can be used in water depths to about 40 metres • Lower installed mooring cost **Cons:** • Tendency for higher critical wave-induced motions • Tends to use more material and larger structures in comparison to other concepts • Complex fabrication compared with other concepts, especially spar buoys	**First movers** **Principle Power (WindFloat)** • Demonstrated in Portugal in 2011 (2 MW); major shareholders include EDP Ventures and Repsol Energy Ventures **Fukushima FORWARD** • Demonstrated in Japan in 2013 (2 MW) and 2015 (7 MW); major shareholders include Marubeni, Mitsubishi, JMU, Mitsui and Nippon Steel **Fast followers** **Ideol (Floatgen)** • Planned demonstration in France in 2017 (2 MW); project partners include Bouygues Travaux Publics and EC FP7 **Hexicon** • Planned demonstration in UK in 2018 (two ~5 MW turbines on a single platform) **Other players (examples)** Aerodyn, DCNS/GE, DeepCwind, Floating Power Plant, GustoMSC, NAUTILUS Floating Solutions, Nenuphar/ EDF, TetraFloat
Tension leg platform Highly buoyant, with central column and arms connected to tensioned tendons which secure the foundation to the suction / piled anchors. **Pros:** • Tendency for lower critical wave-induced motions • Low mass • Can be assembled onshore or in a dry dock • Can be used in water depths to 50-60 metres, depending on metocean conditions **Cons:** • Harder to keep stable during transport and installation • Depending on the design, a special purpose vessel may be required • Some uncertainty about impact of possible high-frequency dynamic effects on turbine • Higher installed mooring cost	**First movers** GICON • Demonstrated in Germany in 2016 (2.3 MW); technical partners include TU Bergakademie Freiberg, Rostock University and Fraunhofer IWES **Fast followers** Glosten Associates (PelaStar) • Currently seeking site for 6 MW demonstration • Other players (examples) • Blue H Group, DBD Systems, Iberdrola, Nautica Windpower

Path to market

A robust go-to-market strategy is critical for overcoming the barriers described above. For floating foundations, large deep-water markets are characterised by high population density near coastlines, deep water and highly developed economies. Japan, the US west coast, Western Europe and the Republic of Korea often top the list of attractive end-game markets for floating foundations.

These markets, however, are not necessarily good places to develop and operate pre-commercial projects. As with many new technologies, stepping stone markets may be needed for floating foundations. Stepping stone markets are based on strong product-market fit during the early stages of technology development.

For floating foundations, stepping stone markets are likely to display some or all of the following features:

- Limited onshore domestic energy resource (scarce or expensive fossil fuels, lack of space for solar and onshore wind development)
- High electricity prices (USD 300-500 per megawatt-hour retail)
- Deep-water coastline
- Progressive government, looking to take pro-active steps to rapidly de-carbonise its economy
- Sufficient port and supply chain capability within reach.

Recommended actions

Participation from policy makers, investors, researchers and industry is imperative to the success of floating offshore wind.

Policy makers need to accelerate floating-specific project development frameworks to keep pace with technology development, recognising the time scales needed for project development. They also need to facilitate maximum private investment, including through continued use of proven mechanisms focused on pre-commercial technology, such as extending support to demonstration plants, and providing sufficient confidence and visibility in future markets.

Investors need to be patient about returns on investment. This tends to demand a deeper understanding of long-term potential and profitability.

Researchers should focus on cost and risk reduction across the entire offshore wind project cycle. This includes whole-system modelling and optimisation, taking well-characterised site conditions into account, and learning from wind resource and power-output measurements from early projects.

Industry needs to continue finding ways to collaborate (share risk) and, in the longer term, to consolidate to bring the best technologies together at reasonable total cost and risk. Industry also needs to provide transparency regarding cost and risk to the other stakeholders.

Figure 2: More than one turbine can share a single floating foundation.

Illustration courtesy of HEXICON

Bibliography

- The Carbon Trust (2015), "Floating Offshore Wind: Market and Technology Review", Prepared for the Scottish Government, *www.carbontrust.com/media/670664/floating-offshore-wind-market-technology-review.pdf*
- The Crown Estate (2012), "UK Market Potential and Technology Assessment for Floating Offshore Wind Power", *www.thecrownestate.co.uk/media/5537/km-in-gt-tech-122012-uk-market-potential-and-technology-assessment-for-floating-wind-power.pdf*
- European Wind Energy Association (2013), "Deep Water: The Next Step for Offshore Wind Energy", *www.ewea.org/fileadmin/files/library/publications/reports/Deep_Water.pdf*
- IRENA (2016), "Innovation Outlook: Offshore Wind", *www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Offshore_Wind_2016.pdf*
- ORE Catapult (2015), "Floating Wind: Technology Assessment", *https://ore.catapult.org.uk/wp-content/uploads/2016/05/Floating-wind-technology-assessment-June-2015.pdf*
- US Department of Energy (2015), "Wind Vision: A New Era for Wind Power in the United States", *www.energy.gov/sites/prod/files/WindVision_Report_final.pdf*

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Report Contributors: Kate Freeman, Giles Hundleby, Charles Nordstrom, Alun Roberts, Bruce Valpy and Chris Willow (BVG Associates), Philip Totaro (Totaro and Associates), and Maria Ayuso and Francisco Boshell (IRENA).

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