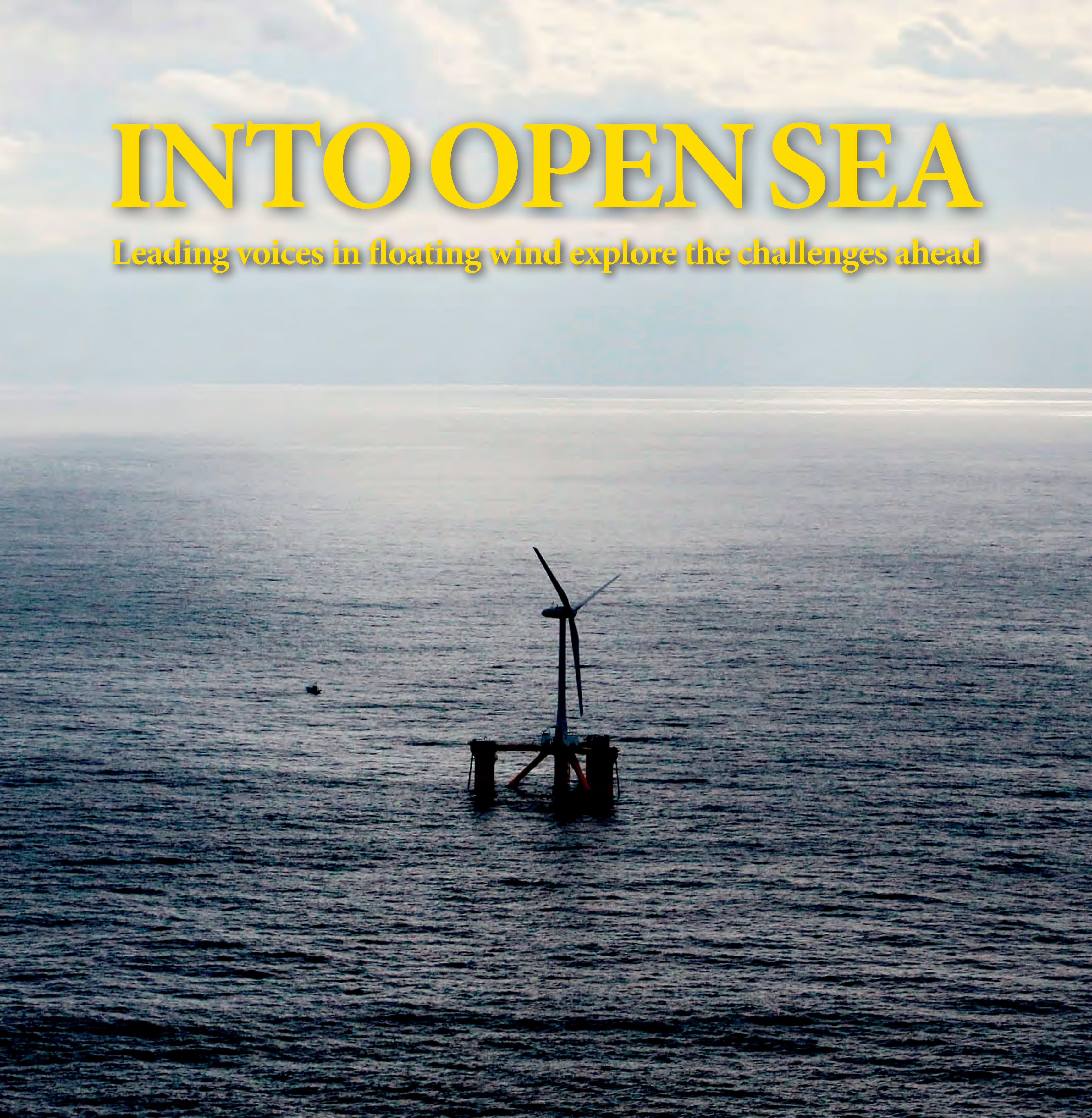
RECHARGE

THOUGHT LEADERS DOSSIER

FOWT 2018 SPECIAL

INTO OPEN SEA

Leading voices in floating wind explore the challenges ahead



IN THE BEGINNING: The Hywind 1 pilot turbine being towed out to its project site back in 2009

Floating wind dream now a reality

Darius Snieckus
Editor-in-Chief, *Recharge*

My first press trip after we launched *Recharge* in 2009 was to see the Hywind prototype. I felt then, ploughing through the waves in the Norwegian North Sea, as now: that there is something in floating wind power that touches an ancient aspect of the human psyche. Perhaps it is our seagoing instinct that it speaks to, the voyage out from *terra firma* to the edge of the world, to conquer foreign lands, to the Great Unknown.

Sea power has found new meaning in the offshore wind industry, which in the blink of an eye has slashed its cost of energy down to the point where it will be as inexpensive as onshore within five years, and soon cheaper than any fossil fuel.

But it is floating wind that has the potential to churn out many hundreds of gigawatts around the globe and power the planet's ever-growing coastal cities.

A recent study out of the US calculated that winds streaming over "deep ocean" waters beyond the reach of fixed-bottom turbines could one day provide 18 terawatts of power, what the authors called "civilisation-scale" energy production.

Until last October — despite the flagship floating turbines installed off Europe and Japan — this was all a vision. Then, Statoil powered up its 30MW Hywind Scotland project in the UK North Sea, stating it expects to build 500MW developments before 2030, as costs plunge to €40-60 ($46.60-69.95) per MWh — where conventional offshore wind is priced now.

A week before Hywind's switch-on, across the Atlantic, further proof of floating wind's arrival came with the christening of the EU FloatGen, a 2MW test unit designed by Ideol, which has a multi-gigawatt pipeline of orders in the UK, France and Japan.

> To read this collection of thought leadership pieces is to feel that the spirit of offshore adventure is alive and well

In recent months, the pace towards industrialisation has quickened, with offshore oil contractor Aker Solutions buying into Principle Power and compatriot Kvaerner setting up a collaboration with Ideol. And in April, Aker and EDPR announced they would construct a 150MW floating wind farm off the US west coast by 2024.

A year ago, analysts were talking about a global floating wind market of 3.5GW by then; now the consensus is 5-6GW, with the UK's Carbon Trust among those forecasting as much as 12GW.

Navigation from here — as Statoil New Energies chief Irene Rummelhof put it after the inaugural Hywind Scotland flyover last autumn — now depends on "the next project — and the next project".

For the floating wind industry, the challenges ahead will be nothing short of elemental. As novelist Joseph Conrad wrote: "The sea has no generosity. No display of manly qualities — courage, hardihood, endurance, faithfulness — has ever been known to touch its irresponsible consciousness of power."

But to read this collection of thought leadership pieces, which *Recharge* editors have curated for our first Floating Wind Power Players supplement, is to feel that the spirit of offshore adventure is alive and well — and that the sector will more than measure up for the journey into becoming a mainstream energy source. God Vind!

Photograph | Statoil

PIONEERING: Statoil's 30MW Hywind Scotland project

Photograph | Statoil

CONTENTS

Contributors

Henrik Stiesdal
The former chief technology officer at Siemens Wind Power is the founder of Stiesdal Floating Technologies

Sebastian Bringsværd
The head of Hywind development at Statoil is in charge of deployment and commercialisation of the Hywind concept

Paul de la Guérivière
The chief executive of floating wind specialist Ideol has developed and financed renewables projects across the world

João Metelo
The chief executive of floating wind designer Principle Power is a former executive vice-president at EDPR

Jérôme Guillet
The Frenchman has been managing director of renewable-energy financial advisers Green Giraffe since 2010

Martin Jakubowski
The chief executive of two-bladed turbine OEM Seawind has led innovative renewables companies since 1997

Bill Hurley
The chairman of US engineering firm and tension-leg platform designer Glosten is a naval architect by trade

Trond Landbø
Landbø is manager of the renewable energy business area at Norway-based engineering firm Dr.techn.Olav Olsen

Joost Heemskerk
The Dutchman is renewable energy product line director at oil & gas floating tech firm SBM Offshore

Rhodri James
The Briton is manager of policy and innovation at UK non-profit organisation The Carbon Trust

Chris McConville
The general manager of Floating Power Plant McConville is the first chairman of Friends of Floating Offshore Wind

Eoghan Quinn
The global wind lead at engineering firm WorleyParsons is a former advisor to the Scottish Government

Floating wind can mirror vital cost cuts made by bottom-fixed industry

Henrik Stiesdal is a former chief technology officer at Siemens Wind Power and the founder of Stiesdal Offshore Technologies

HENRIK STIESDAL

Floating wind power has clearly proven its technical viability. Prototypes and pilot farms operate reliably, and the potential technical challenges that ten years ago appeared quite daunting have been ticked off one by one. Turbines do not become unstable during operation (most of us have forgotten that this was actually a very tangible worry before the first prototypes), nacelle accelerations can be kept within acceptable limits, mooring and access systems do work as intended, and soon.

However, the floating offshore wind industry has yet to prove its financial viability. Cost levels remain prohibitive for large-scale applications, and mass production tends to be considered as an afterthought. Many designs are manufactured using conventional, non-industrialised methods, weights are measured in thousands of tonnes, manufacturing times are measured in months, installation often requires lengthy use of expensive dry docks or heavy-lift vessels, and mooring systems tend to be entirely based on the legacy from the offshore oil & gas sector. Typically, mass production will require very substantial investments.

The floating offshore wind industry is not the first sector to face challenges of this nature. Many other industries have started out at unsatisfactory cost levels and have become competitive through the learning curve, gradually improving design and manufacturing technologies, shaving off costs along the way. The problem is that we start at a high cost level, and that the benchmarks defined by cost competition from other renewable technologies keep moving downwards.

> We don't have to go through our own learning curve in the conventional way

It doesn't have to be that way, however. We don't have to go through our own learning curve in the conventional way.

Those of us deeply engaged in development of floating foundations only have to lift our eyes to get the necessary inspiration. The wind turbines fitted to our foundations are supplied by an industry that has faced similar challenges — and has solved them.

Only a few years ago it seemed that offshore wind power was decades from reaching grid parity. Now, the new norm is zero-subsidy bids. In 2012, most of us in the industry would have responded with a "Yeah, keep on dreaming!" if somebody had predicted that five years later, governments would have to devise new methods of comparing bids, because the bidders would be asking for the same subsidy, ie, none. Actually, thinking back, I don't recall anybody making such a prediction.

What I do recall from 2012 is the discussion about whether we as a joint industry could make a statement to the effect that by 2020 offshore wind would reach a cost level below €100/MWh. Personally, I was a strong proponent of making such a statement, because I felt it was politically necessary, but many of my peers were concerned that it might be too optimistic and that we would not be able to deliver as an industry. Now that discussion seems almost archaic.

The dramatic cost reductions are not the result of one single factor. Needless to say, if one factor were to be singled out, it would be the oldest cost-reduction motivation in the book — competition, arising as a result of the auction systems.

Other factors are more circumstantial, such as low steel prices and low interest rates. But even under the competitive pressure and with the benefit of low steel prices and interest rates, we would not have reached the present cost levels without contribution from more substantial, industry-driven factors.

The most important one is the industrialisation of the whole value chain. Even for the large wind turbines used offshore, components are now manufactured in serial production, not in batch production. Assembly takes place in well-organised factories, if not in true assembly lines then at least in smooth, continuous operation. Operations in the port of embarcation and at sea take place according to well-established procedures. As a result, the uncertainties related to the installation of a large offshore wind project are now much lower than before, and skilled developers are able to fine-tune their budgets accordingly, trimming the stacked contingencies that formerly served as significant cost adders.

In short, the conventional offshore wind industry has been through a good part of its learning curve. There are still improvements to make, but the largest strides have been made.

Let us in the floating wind industry benefit from the conventional wind industry experiences and solutions. Let us leapfrog the learning curve!

We can do that by insisting that our designs must be suited for the application of proven design and manufacturing technologies from the wind turbine industry. Manufacturing must take place in existing factories using industrialised methods, components must be transportable by road, and quayside assembly must be no more complex than the parallel on-site assembly of the wind turbines.

We can supplement this approach, which will by nature have individual elements for the different concepts, with a joint effort on the commonalities, such as anchors and mooring systems, dynamic cable arrangements, boat landings, crew transfer systems and operations and maintenance arrangements. There is no need for each of the many designers of floating systems to each develop their own secondary technologies.

To extend the metaphor, industry-wide cooperation can be a springboard in the leapfrogging of the learning curve.

I am of the firm opinion that through a combination of the application of the learnings from the established offshore wind industry and a joint effort on the industrialisation of the secondary equipment we can reach genuinely competitive cost levels much earlier than if we as an industry have to go through our own learning curve.

Let us leapfrog together!

Photography | Stiesdal Offshore Technologies | Ørsted

FAST TRACK: Artist's impression of the proposed industrialised assembly of Stiesdal Offshore Technologies' TetraSpar foundation. *Opposite:* the last blade goes up at the Anholt offshore wind farm off Germany

The critical question of how to finance commercial floating projects

Jérôme Guillet is managing director of Paris-headquartered renewable-energy financial advisers Green Giraffe

JÉRÔME GUILLET

Floating wind power projects are moving from the prototype phase to commercial endeavours, so the question of how they will be financed is becoming critical. Utilities and technology providers may have been willing to bear the cost of demonstrators on their balance sheets, but if they want third-party funding for their next projects, they will need to mitigate the risks these financiers are asked to bear and get external validation of the technology.

It stands to reason that lenders and investors will work from what they know (offshore wind projects with bottom-fixed foundations), and try to understand how different floating wind is from a risk perspective.

The good news is that fixed-bottom offshore wind is something that both lenders and investors are quite comfortable with and the risk analysis with respect to items such as turbine technology, regulatory context and price regimes will be based on what has already been done.

The focus will naturally move to the foundation technology, raising questions from "does the technology work?" to "can enough of these gigantic structures be built on time?" or "is it doable and cost-effective to bring turbines back to shore to do repairs?".

If the technical answers to these questions are satisfactory, then the focus will move to the contractual responsibility of parties — "can the responsible party be identified if problems arise?", "will there be a risk of disputes between the turbine supplier and the foundation provider?" or "are the foundation suppliers strong enough, financially, to provide the necessary guarantees backing their technology?".

> It stands to reason that lenders will try to understand how different floating wind is from a risk perspective [to bottom-fixed offshore]

Fixed-bottom offshore wind forced financiers to deal with multi-contract construction set-ups, and to understand the corresponding interface risks. Financiers have accepted these risks, but are always very careful about it. Here, with floating wind, we are again in a multi-contract situation, but with a new set of interfaces and risks that financiers will need to get comfortable with.

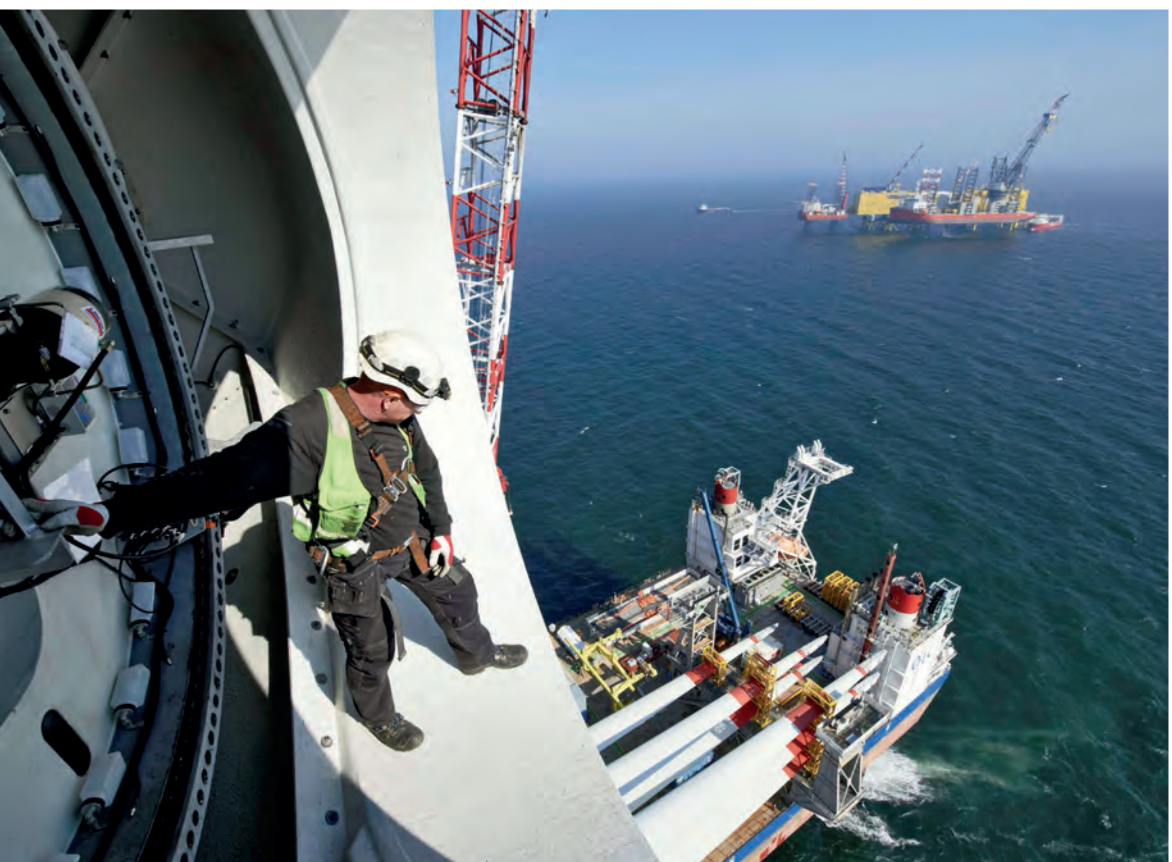
Full co-operation from the turbine supplier is needed to delineate the integrated design requirements and to confirm the acceptability of the substructure's performance. Further, the integrated design must be certified by a reputable classification body. Logically, the availability guarantees (for both the turbine and the foundation), together with the power curve warranty, will be the key items to be negotiated.

Conversely, the risk allocation during construction is likely to be simpler than in fixed-bottom projects, as most of the construction work can be done onshore, with very limited weather risk and a more straightforward installation process.

In any case, the well-known principles of contractual strategy, which have facilitated the project financing of fixed-bottom projects can be applied to floating wind as well, such as distributing the project scope of work in well-defined contract lots (priced on the basis of fixed-lump-sum amounts), including delay damages and delay schedule rates in the contracts, and putting in place liability caps high enough to compensate all losses resulting from delays, should a contractor underperform.

The track record of the chosen floating wind technology and the strength of the industrial counterparties will play a major difference in the eyes of the investors and lenders: the technologies that have a satisfactory operating track record from large-scale demonstrators already installed are more likely to be financed on a non-recourse basis.

Ample contingency budgets, for both the construction and maintenance phases, together with a comprehensive insurance package, will be standard but essential



components of the contractual and financing package.

An aspect which is interestingly different from fixed-bottom is that floating wind will take place in countries with a very different political context. Support for renewables in places like Taiwan, the US or Spain is either untested or has been subject to serious vagaries, and projects have seen serious obstacles, including challenges to permits or, as in Spain, retroactive changes to price regimes.

Financiers will want to be comfortable that a specific tariff regime for floating wind is in place and is politically sustainable — there must be a good enough strategic rationale to develop the technology in the country, with demonstrated public support for that, and sufficient marketable local content. Either way, investors will likely want to see multilateral financing institutions involved in the early projects to provide for some level of "political cover".

It is likely that the commercial terms of the first floating wind deals will be guided by the traditional offshore wind market precedents, but end up, at least for the initial deals, with substantially more conservative terms.

We believe that funding could be available to the forthcoming round of early commercial floating wind projects, subject to strict conditions and realistic expectations. This means that the cost basis of these early projects is not going to be the most competitive, as funding will not be on the most aggressive terms.

Such early deals will nevertheless be vital for the industry as it will allow the track record for commercially proven floating wind to start, which will give comfort that subsequent deals can be done with more optimistic assumptions and thus more favourable terms.

TESTING THE WATERS: The Fukushima Forward pilot project off Japan in 2013; *opposite:* the construction of the Nordsee Ost wind farm in the German North Sea

Photography | Senvion | AFP/Getty

Industrialisation, scale and next-generation technology will cut costs

Sebastian Bringsværd is head of Hywind development at Statoil

SEBASTIAN BRINGSVÆRD

READY FOR LIFT-OFF: The five turbines destined for Hywind Scotland are assembled at the port of Stord, Norway, prior to installation on their floating foundations

Photograph | Statoil

Statoil has a firm belief that the future of offshore wind is floating. By going deeper and further offshore where wind resources are better, an energy source with an almost unlimited potential can be harnessed. Floating wind is encouraged by — and will build on — the tremendous success of the bottom-fixed offshore wind and offers a complimentary source of energy. Our experience developing our Hywind technology — both the original prototype, installed off Norway in 2009, and the 30MW array off Scotland, the world's first floating wind farm — bears this out.

The five Siemens Gamesa turbines at Hywind Scotland have performed spectacularly so far. Despite one hurricane, one winter storm bringing with it 45 metre-per-second (160 km/h) winds and wave heights of up to 8.2 metres, these 6MW units have shown capacity factors averaging around 65% turbines, as compared to conventional offshore wind farms which operate 45-60%.

This is a heartening start. Now we need more projects to truly industrialise the technology. So we are looking at possible developments off Europe, Asia and North America. And our minds are open: the next Hywind project could be a utility-scale wind farm — but it might also be one that powers an oil and gas installation, for instance, or a remote island.

Whatever we do next, cost is in the crucible. For floating wind to succeed, the levelised cost of energy (LCOE) has to come down, and by setting ambitious but realistic LCOE targets —we believe by 2030 €40-60/MWh is achievable — Statoil will create confidence among customers, suppliers and other stakeholders that floating wind will be a competitive energy source with a huge long-term potential.

Cost reductions in the floating offshore wind industry will be accomplished through the following key areas: industrialisation — optimising designs of substructures and moorings and reducing the cost per tonne towards mass production levels; economies of scale — larger wind farms will drive down costs for infrastructure and logistics; upscaling — follow the bottom-fixed industry towards turbine nameplates of 10-15MW; and technology development — establishing new and more efficient methods for installation, operation and maintenance — and energy storage.

I single out the last of these technologies for special mention. It is widely believed industrial-scale batteries — beginning with lithium-ion technology — will be key to future power systems, and with more renewables coming on to networks, crucial to handling storage to ensure stability and reliability of supply.

> It will require dedicated and coordinated efforts of suppliers, developers and governments

We started our Batwind project with partner Masdar with this in mind. The purpose of the pilot is to "teach" a battery, which we connected to Hywind Scotland earlier this year, when to hold back and store electricity, and when to send power to the grid, so as to 'increase the value' of the power from the floating turbines.

Being able to study Batwind's performance under a range of conditions on Hywind Scotland will generate a high level of operational data.

The experience, insight, data, models and partnership relations will all be factored in to business development activities that should enable a better value-proposition to customers, while creating a high penetration of renewables in electricity markets as well as increasing the competitive strengths in technology-neutral auctions.

Our Hywind technology shows every sign of being a step-change in the industry's approach to offshore wind power — but we are just getting going. And it will require dedicated and coordinated efforts of suppliers, developers and governments to make floating the future of offshore wind. Statoil has set out a direction and we call for other developers to follow, for the supply chain to prepare, and for governments to establish framework conditions that will enable the industry to grow. A growing floating wind industry will create jobs, be a secure source of energy and reduce CO_2 emissions. R

Experience is needed to reduce risk and attract contractors and lenders

PAUL DE LA GUÉRIVIÈRE

Paul de la Guérivière is chief executive of French floating wind specialist Ideol

Floating wind is at a real turning point. This burgeoning, yet fast accelerating, industry will now be focusing on the implementation of several pre-commercial projects during the next two to three years, following the encouraging return on experience of a first phase of single-unit demonstrators in Europe and Japan.

Why are these pre-commercial projects so important? Why does a company like Ideol, with two full-scale demonstrators in both Europe and Asia, find it necessary to be involved in the upcoming EolMed pilot project in France?

Apart from introducing a batch of second-generation innovations, design optimisations and benefiting from the experience of working with a commercially available offshore wind turbine, the first interest of these pre-commercial projects is to test and validate the whole contractual structure of a floating project as well as the contractual interfaces between the different suppliers. Such return on experience is needed to have contractors endorse an educated liability risk with future commercial-scale projects and for lenders to provide financing.

The contractual structure of a floating wind project is very similar to a traditional bottom-fixed one, with the same Tier 1 contracts. But some variations are needed to integrate floating-specific parameters including the potential impact of the floater movements on the turbine performance, and the management of the partial handovers between the turbine and the floater suppliers — first for the wind turbine integration then for the whole-system offshore installation.

A good illustration of these variations is the definition of the floater performance. Which criteria ought to be used? Maximum tilt angles or accelerations at the nacelle hub? Maximum loads on key turbine components? Floater real-response amplitude? Other criteria? The answer might not be so intuitive. Take the impact of the floater movements on the platform accessibility or the potential sea sickness of the maintenance team for example, having a rigid floater is perhaps not the optimal option.

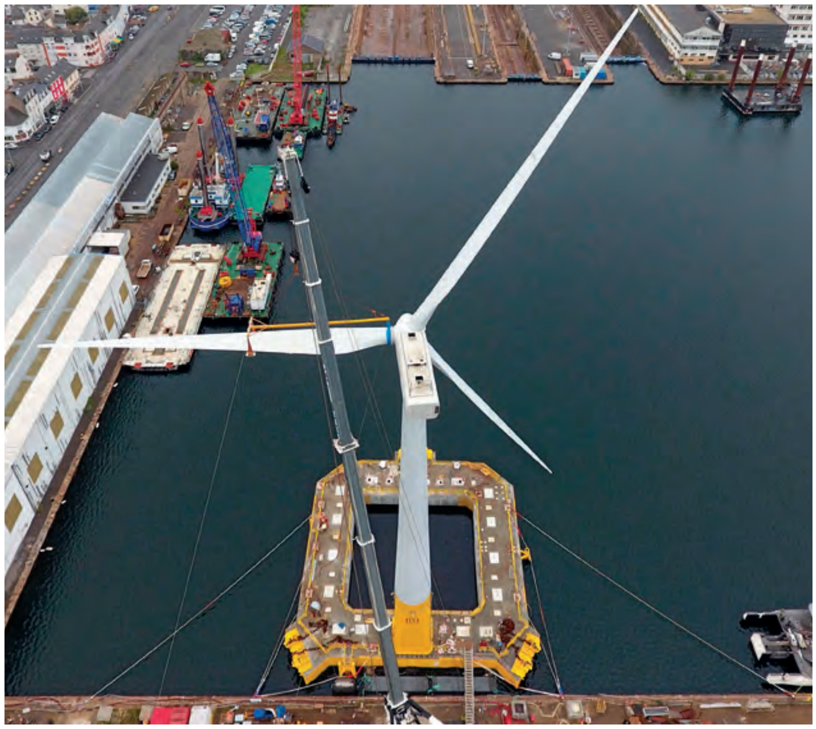
It is essential that the upcoming pre-commercial projects in France and Portugal — where there is a clear separation between the project owners and the suppliers — help test and benchmark contractual solutions for the benefit of the whole industry.

A second key and invaluable feature of pre-commercial projects is the testing and validation of the construction and supply chain needed to implement a serial production of 50-plus units. This challenge should certainly not be underestimated in terms of manufacturing capacity, logistics constraints and organisation, as underlined by Hywind Scotland where components have travelled from Spain to Norway and then to Scotland for installation. Despite the burden of selecting concrete (versus steel) for the construction of the four floaters for our EolMed project, we are convinced that it will definitely help pre-planning serial production, identifying the key logistics risks and demonstrating the benefit of our risk-mitigation strategy to potential lenders and investors.

Floating wind is no longer a question of identifying the right innovative solutions but increasingly more a question of having these innovative solutions implemented within the right legal, project-financing and serial-production frameworks following both full-scale demonstrators and pre-commercial returns on experience.

These considerations are without a doubt a sign that the floating wind industry is maturing and that some solutions are starting to have an edge over others.

> Floating wind is... increasingly a question of having innovative solutions implemented within the right legal, project-financing and serial-production frameworks



Photograph | Ideol

SQUARE ONE: Ideol's prototype 2MW Floatgen substructure in Saint-Nazaire, France

Why two blades are better than three for floating wind turbines

Martin Jakubowski is chief executive of two-blade turbine OEM Seawind

MARTIN JAKUBOWSKI

It is understandable that the offshore market started in the relatively shallow North and Baltic Sea. But the global market for offshore wind in the future is mainly in deeper waters — and therefore floating.

A 2009 study commissioned by the UK's Energy Techologies Institute found that in 16 key countries with regulatory frameworks in place for offshore wind (which excluded China), the potential in waters 30-300 metres deep was 8,640GW — much bigger than the potential in shallow waters. Of the 8,640GW, 3,914GW was in water depths of 100-200 metres.

Many floating solutions are under development or have been tested, such as the tension-leg platform, the spar buoy, the semi-spar hybrid solution or the semisubmersible. Our understanding, based on the analyses carried out so far, is that the semisubmersible, made of concrete, is the most cost-effective solution, considering the issues of fabrication, installation, operation and expected lifetime. However, even this solution can cause, in operation, harmful loads to the supported turbine if this has a rigid rotor rather than a flexible rotor with a teetering hinge.

In 1975, when US president Jimmy Carter assigned $330m to NASA to research on wind turbines after the first oil shock, NASA and the US industries participating in the programme, such as Hamilton Standard (today UTC), Boeing and GE came to the conclusion that two-bladed wind turbines deliver better economics than three-bladed. Fundamental for two-bladed wind turbines, however, is the introduction of a teetering hinge or cyclic pitching. We know today that two-bladed wind turbines would hardly be accepted onshore because of the higher noise emissions and level of flicker. Offshore, these disadvantages are of less importance.

> The benefit comes from the fact that no dynamic moment can be applied by the rotor to the drivetrain

Later on, in the 1990s, Glidden Doman, head of several two-bladed R&D projects in the USA, in Sweden and in Italy, understood that by introducing an elastomeric teetering hinge, he could eliminate the need for blade pitching.

The feasibility of the concept was substantiated by a 1.5MW two-bladed, teetering hinge, yaw-control prototype, installed in Italy. Since then, that turbine technology has been largely improved within Seawind under the lead of Silvestro Caruso, who cooperated with Glidden Doman on the Gamma 60 prototype.

The benefit of a two-bladed teetering hinge turbine on a floating foundation comes from the fact that no dynamic moment can be applied by the rotor to the drivetrain. This enormous benefit is due to the "passive" action of that hinge placed between the hub and the main shaft. In the floating condition the dynamic displacements of the turbine tower (pitch, surge,

The fundamental importance of mooring systems

Bill Hurley is chairman of US engineering firm and tension-leg platform designer Glosten

BILL HURLEY

All floating foundation technologies need a mooring system attached to the seabed. Recognising that bottom-fixed foundations use monopiles or jackets to anchor to the seabed, mooring systems are an important target for the floating wind cost reductions needed to compete against bottom-fixed offshore wind.

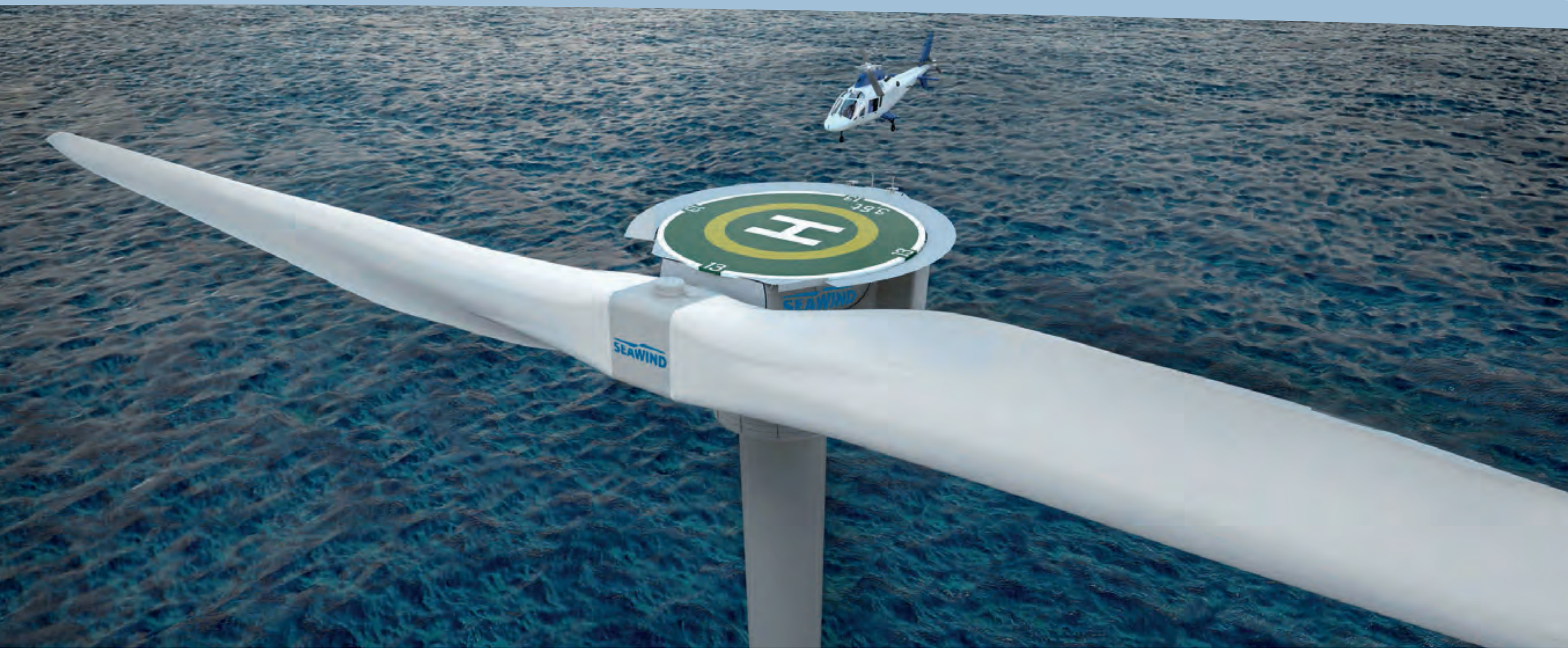
The problem is the large mooring spread required by catenary mooring systems. This mooring spread — the seabed area required for anchoring the unit — expands significantly as water depth increases. For a typical seven-to-one catenary mooring scope, the mooring spread diameter increases 14 metres with every one metre increase in water depth. Hence each turbine in a wind farm of 150-metre water depth needs a 2km diameter seabed area footprint for its catenary mooring system.

The cost and configuration impacts of deeper water catenary systems is significant. Mooring system material costs grow by a factor of seven on water depth. Unit spacing increases well beyond that needed for turbine shadow effects, requiring more lease area, expanding the seabed environmental impact, and decreasing energy density (MW per km^2). Increasing unit spacing has a secondary cost impact as the array cable lengths increase.

A solution lies in taut-line mooring systems and vertical load anchors (VLAs).

Catenary systems hang in a parabolic shape and pull horizontally on drag-embedment anchors or suction piles. Taut system mooring lines run in a straight line between the anchor and platform. Taut system anchors can be pulled in closer to the platform, decreasing the seabed footprint, however the vertical loads on the anchors increase and the mooring system becomes stiffer, impacting the dynamic behaviour of the floating platform. The tension-leg platform represents the minimal footprint where the anchors are under the platform and see only vertical load.

The offshore oil & gas industry has, of course, addressed these mooring-system design issues and have considered and installed taut systems, particularly for long-life deepwater production facilities. The floating wind industry needs to sidestep from oil & gas and develop high-volume low-cost VLA solutions to optimise commercial wind farm configurations,



heave and yaw), due to the actions of the waves and the wind, cause a dynamic displacement of the rotor disc in the case of a (three-bladed) rigid rotor. This, in turn, results in dynamic loading of the shaft. This situation is not given in the case of a rotor (two-bladed) with a teetering hinge. It is significant to see that: (i) For a turbine with a teetering hinge rotor mounted on floating platform, the hub moments are substantially those of the onshore situation; while for a turbine with a rigid rotor (three-bladed) mounted on a floating platform, the maximum hub moments are around 30% higher than in the onshore situation; (ii) the total amount of the hub moments of a rigid rotor turbine mounted on a floating foundation would be 15-20 times higher than those of a teetering rotor turbine mounted on the same floating foundation; (iii) the pitching movement of the floating unit doesn't affect the turbine performance; (iv) in the case of a turbine with teetering hinge on a concrete semisubmersible foundation, the turbine yaw controller is the same as used for an onshore or offshore bottom-fixed machines — this is because the yaw inertia and damping of the concrete semisubmersible floating foundation are quite high.

In summary, we see the combination of a concrete semi-floater such as the OO-Star from Olav Olsen (*see page 14*), in combination with a two-bladed wind turbine with a teetering hinge, as the best configuration to attack the vast deepwater potential. R

PROPELLERS: Seawind's two-blade turbine, complete with helipad

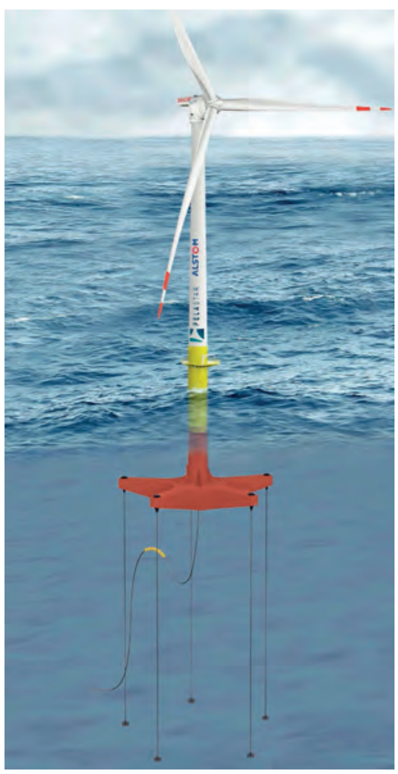
manage cost, and not allow such large cost multipliers as water depth increases.

Oil & gas VLAs have been developed by such companies as Vryhof, Bruce, Delmar and Intermoor, so innovative steps can be taken from a number of existing baselines.

Single-unit floating turbine demonstration projects, and the five-unit Hywind Scotland pilot plant, have focused on platform demonstration and are clearly successful.

However, they have installed catenary mooring systems with drag-embedment or suction pile anchors, deferring the mooring system technology issues to be faced in deeper water and with more units at commercial scale.

The UK's Carbon Trust is to be applauded for its Floating Wind Joint Industry Project, which last year started investigating "the key challenges and opportunities for optimisation in mooring systems for floating wind farms, including both catenary and tension configurations, anchors, and associated auxiliary components". The industry can look forward to its progress.



Continued development of VLAs will benefit all floating foundation technologies and help overall viability, especially in the deeper waters beyond 150 metres.

For commercial-scale projects, the floating wind industry will need to migrate towards taut-line moorings and can do so through innovation steps that lead to effective, cost-competitive VLAs with low material cost and low installation cost.

This is the future vision, where a healthy supply chain exists for anchors, components and installation, and floating wind farms can be configured without mooring system constraints, overall cost is reduced, and cost increases associated with water depth are minimal. R

BOLT UPRIGHT: Glosten's Pelastar tension-leg platform design

Images | Seawind | Glosten


Photo: Dennis Schroeder/NREL

Floaters need the same modularity as seen in oil & gas FPSO units

JOOST HEEMSKERK

Joost Heemskerk is renewable-energy product line director at SBM Offshore

The wake-up call experienced in recent years by the offshore oil & gas industry represents a gift to offshore wind by way of lessons learned in terms of costs, technology and standardisation. Inflated costs, combined with a falling oil price, paralysed projects, forcing a reassessment of a cost base that was no longer sustainable and ignited a wave of innovation for technology and business models.

The key enabler for floating wind is an acceptable levelised cost of energy (LCOE). A big driver for this is a solution whereby more than 50 floating wind units are fabricated, installed and producing power to the grid within 36 months of a final investment decision — with no compromise on quality and safety. This optimum scenario must be feasible across varying global project environments, taking into account supply-chain capabilities and available fabrication facilities at a local level.

This represents an industrialisation challenge of unprecedented scale, requiring floater concepts and technologies to have strong individual operational performance that can be executed for optimised industrialisation on the commercial-scale required.

Granted, the onshore and offshore bottom-fixed wind industries have made great cost-reduction progress over the past 20 years.

Many of its products (eg, the wind turbines and towers) and lessons learned in project execution, logistics and fabrication can be leveraged to the benefit of floating wind's industrialisation. But it is not enough, and floating wind will not be given the benefit of 20 years to catch up on cost levels. Here is where the recent lessons learned in the offshore oil & gas industry come in, combined with its decades of experience in floating energy systems design, project execution, fabrication and supply-chain development, as well as safety and quality.

To benefit from economies of scale, the wind floater design requires modularity, flexibility and adaptability to match the existing supply chain and logistical capabilities for the project at hand.

Floaters' sub-components are designed and optimised to be pre-fabricated in dedicated locations, adapted to their specificities and ideally using existing facilities. It's critical that assembly at a final assembly hub is close to the site location for launch into the water. In order to create an efficient production line and allow high production rates, it is important to rationalise the final assembly steps and lifting operations, to favour 'plug and weld'.

This is a concept that has been progressed for FPSOs [floating production storage and offloading units] in the oil & gas industry by SBM Offshore. By standardising what had been a very prescriptive process, the costs have come down and the time to first oil reduced — essentially by avoiding "reinventing the wheel" on each project .

SBM has found many opportunities to create an FPSO with standardised layouts, components, and equipment. Similar to wind floaters, the key to an optimal FPSO layout is modularisation, and through standardisation SBM has accelerated not only the design process, but also the supply-chain and construction phases. This business model and the technologies used can maximise the time- and cost-saving opportunities and be applied to wind floater components. For example, generic topsides, necessary whatever the field specifics, can be built ahead of time and in a different location to the hull, ie, where the capacity and most cost-effective option lies.

The need to de-risk and achieve an optimum execution model will be central to the future commercial developments. It has to be repeatable and adaptable globally to make the best use of the existing production tools and minimising the investments required.

Floating wind has progressed past the R&D stage and is gearing up for commercial scale, which also requires experienced EPCI [engineering, procurement, construction and installation] contractors — another lesson to be learned from oil & gas.

Such players with performance track record across the project lifecycle and the capability to deliver floating projects on time and within budget, will further contribute to LCOE reduction through industrialisation.

MOBILE OIL: Petrobras' P-66 FPSO unit, off Brazil.

Photograph | Petrobras

How to install supersize floating turbines without the heavy lifting

Trond Landbø is manager of the renewable energy business area at Norwegian engineering firm Dr.techn.Olav Olsen

TROND LANDBØ

The offshore wind market has been able to reduce cost through economies of scale, optimisation, standardisation and industrialisation. The market for bottom-fixed offshore wind is maturing and the energy prices are becoming commercially competitive. The floating wind market is gaining speed in terms of development of new floating solutions and demonstration projects.

The key for further cost reductions within floating wind is to further increase turbine size, to continue moving into deeper waters where stronger and more stable winds blow, to optimise floater and mooring systems and to optimise fabrication and installation methods.

Development of larger wind turbines, of 10-15MW, is continuing and in the foreseeable future we may even see turbines in the range of 20MW. This could, through economies of scale, be an important contribution in the struggle to bring the cost of energy down. On the other hand, this could drive the installation cost up, since current tools and methods will not work for the future generations of wind turbines. In order to install offshore wind in the same manner as used today even larger and more expensive construction vessels will be required.

It has been discussed for a long time whether monopiles could compete in a future offshore wind market with 15-20MW turbines and deeper water. The limitations will be fabrication facilities and installation tools. This may seem like an opportunity for jackets and gravity-base foundations (GBFs) to come in and take over the market. However, jacket structures and GBFs will face much of the same installation challenges as the monopiles. The foundations themselves may be installed more cost-effectively, but installation of the steel tower and the turbine must be done in a similar way as for monopiles and with rotor and nacelle assembly weighing 1,000 tonnes and installed at 150-200 metres above the water surface.

There have been efforts to assemble foundations and turbines onshore and to develop tools or methods to bring them offshore and install them as one unit. This may seem like a way to avoid the large cost related to offshore lifting operations. However, the cost of these tools or methods are often higher than the offshore lifting alternative and will be even more expensive in the future when turbines grow in size and weight.

TAKING THE PLUNGE: Olav Olsen's OO-Star concrete semisubmersible design

Image | Dr.Techn.Olav Olsen

One example related to GBFs is to shape the tower as a wide bottle to gain more buoyancy and stability in order to allow for stable tow to the site. The result is that the foundations are optimised for the transport phase and the operation phase will see a great penalty due to higher wave loadings and use of large amounts of solid ballast to make the GBF stable.

Another example is to use temporary buoyancy elements which have to be mounted onshore and demounted offshore and will require expensive connection features.

With the larger turbines coming, we do not see how to avoid expensive offshore lifting operations for any bottom-fixed offshore wind turbine. At least not without imposing very expensive alternative solutions.
This will be the opportunity for floating wind in the future, and for shallow floating concepts — such as semisubmersibles and barges — in particular. Through R&D projects, semisubmersibles are now being proven for floating wind, and can be tuned to equally favourable motions as the deep-draught Hywind spar concept. The great advantage of the semisubmersible is that it can be fully fabricated, assembled and even tested quayside by use of land-based equipment only, and without the requirement for deep waters. This will also be the case when the turbines grow to 15-20MW.

In short, the semisubmersible concept is optimised for the operation phase, which is the main purpose of the floating wind turbine. Due to its nature, the semisubmersible, fully assembled, will be able to solve all temporary phases without any changes to the floater or use of additional tools.

When we also bring in the great potential for standardisation and industrialisation of floating wind turbines, we believe that the future of offshore wind will be floating. Bottom-fixed foundations will be too dependent on water depths and soil conditions, and it will thus be difficult to utilise the full potential for mass fabrication. Floaters, on the other hand, will have a quite standardised design for a given turbine, while the mooring systems and anchors will be the variables. This will ensure a much more robust business case when developing mass fabrication and assembly facilities.

So why should the offshore wind industry move in a direction where it will heavily rely on heavy-lifting marine contractors in the future? We all know what has been going on for years in the oil & gas industry, where a few major heavy-lifting contractors have been operating the largest heavy-lift vessels, leading to limited competition and high costs. By moving to shallow-draft floating turbines, offshore wind can avoid paying premium rates for expensive, weather-sensitive and risky offshore operations.

UK government needs to provide floating sector with route to market

CHRIS McCONVILLE

Chris McConville is chairman of Friends of Floating Offshore Wind and general manager of Floating Power Plant (FPP)

The Friends of Floating Offshore Wind (FOFOW) was founded in May 2016 to bring together leading players in the sector to jointly overcome common challenges by defining support requirements and lobbying for such backing in the UK. We now have a diverse membership including 19 technology pioneers, project developers and supply chain contractors (*see below*), and remain open to new partners.

FOFOW shares the vision that offshore wind is on the advent of a global surge in demand now that levellised cost of energy prices are approaching parity with wholesale electricity market prices — via 'zero subsidy' projects — as well as an increasing pressure to replace carbon-emitting plants with clean generation to comply with climate change commitments.

Not all new offshore wind capacity will find shallow waters and suitable seabed sites, as seen in developments to date, so a large part of this demand will be for floating wind. This growth will benefit the economies of scale for both bottom-fixed and floating solutions.

We believe the achievements made by the floating wind industry in recent months must be built upon to realise commercialisation and provide an option for the growth of offshore wind in the long-term.

The opportunities for the supply chain are clear and the experience gained during the early stages of the industry have the potential to provide significant export markets for early movers. Floating wind also offers greater prospects for diversification from oil & gas given the relatively high correlation between the technical solutions on offer.

As current support in the form of 3.5 ROCs (Renewable Obligation Certificates) in Scotland closed to new entrants in March 2017, FOFOW seeks a commitment from the British government that it will offer the technology a route to market, potentially through a "sector deal" — either separately or as part of the wider offshore wind sector deal.

Though FOFOW fully subscribes to the need to provide continued support to such a promising emerging technology as floating wind — and in recognition of recent requests to extend the ROC support system for certain projects in the sector — we would urge government to consider a longer-term solution that would help the UK remain at the forefront of the global offshore wind market's progress.

While offshore wind will be able to build on the achievements of bottom-fixed developments, some support has been required to reach this point, as has been the case for all emerging energy technologies. As with conventional offshore wind, the employment and industrial opportunities offered by floating wind will far outweigh the short-term costs considerations.

Conversely, a lack of a follow-on support mechanism after ROCs is very likely to result in the industry turning to other markets such as France, Norway or Japan, where floating wind is being strongly backed.

Focus should be trained on the wider socioeconomic benefits of floating wind, the return on investment to a national economy through local gross value added, and job creation in pilot, pre-commercial and commercial scale projects.

Further to this, FOWOW calls on industry to collectively commit to setting targets for the development of floating wind, which the UK government and its devolved administrations can provide the route to market for. This would set out a position to retain a leadership role in the development of such ocean energy technologies and provide the confidence required for the supply chain to continue to invest and develop in the sector.

We believe a target of 1GW — to be realised through various pilot and pre-commercial scale projects commissioned and in advanced levels of development — by 2025 and 5GW by 2030 are realistic stretch targets.

The UK government-industry body the Offshore Renewable Energy Catapult, in a recent project, forecast that floating wind farms would be "common" off Britain by 2030 as part of a "backbone" supply of offshore wind energy from around the British Isles that could meet over 15% of demand.

Westminster has the power to support this vision. FOFOW wants to help make this happen.

Friends of Floating Offshore Wind is made up of RES, Ideol, FPP, JDR Cables, Atkins, Gicon, Hexicon, Cobra, MacAskill Associates, Glosten, Principle Power, Bam Nuttall, DNV GL, Fred Olsen, Intermoor, Fugro, SBM Offshore, Atlantis Resources and BMT.

MAN WITH A PLAN? UK energy secretary Greg Clark

Photography | Getty

Industry collaboration will be key to unlocking commercial projects

Rhodri James is manager of policy and innovation at UK non-profit The Carbon Trust

RHODRI JAMES

The floating offshore wind sector is building considerable momentum on the back of a series of landmark developments in recent years, most notably with the commissioning of Hywind Scotland. However, the transition to full commercial deployment in an increasingly competitive energy landscape is a major challenge facing the industry. Policy, technology, and commercial barriers remain and the industry must present a compelling business case to secure the support it needs to ensure that the current momentum turns into tangible commercial opportunities.

Market growth and policy support

Heightened interest in floating wind has manifested in several ambitious projections outlined by industry players, with Statoil predicting up to 12GW of installed floating wind capacity by 2030. However, political uncertainty post-2020 presents a risk. Given typical project development time frames of seven to ten years, delivering the first commercial projects by 2025 requires development to start now. Suitable sites need to be identified and a supportive policy and regulatory environment developed that sends a clear signal to the market and builds a pipeline of investment opportunities.

Building a business case

In the current climate, few policymakers are willing to risk increasing consumers' energy bills or committing public funds to pay for the commercialisation of a technology that may happen elsewhere. To secure support for a clear route to market, the industry must produce a compelling business case that can chime with several government objectives. The age-old energy trilemma of low energy costs, improved energy security, and low environmental impact prevails, but it is increasingly becoming a quadrilemma. The need to align with an industrial strategy that maximises benefits for domestic companies and revitalises regions suffering industrial decline is an increasingly important political and economic driver.

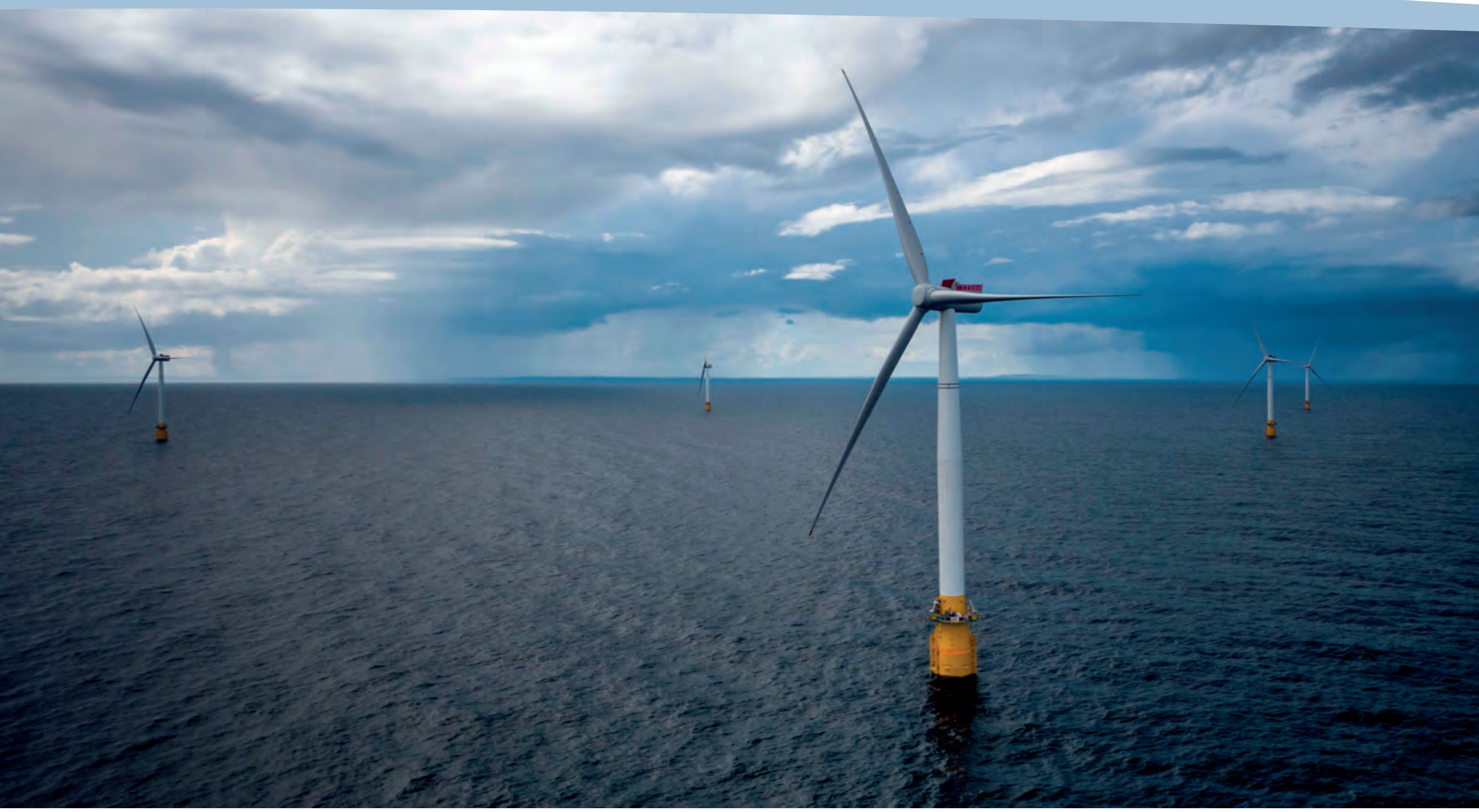
Fixed-bottom offshore wind has proven its ability to deliver against all of these and is expected to be rewarded in the form of increased deployment on a global scale over the coming decade. There is good reason to believe that floating wind can not only emulate this, but can facilitate accelerated growth in new markets and regions where securing low-carbon electricity at low cost for energy-intensive coastal populations is a growing priority. However, technology deployment at scale will be critical if the journey to low-cost, low-carbon generation is to advance.

From demonstration to full commercialisation

The viability of the technology has been proven at prototype and pilot array, but large-scale deployment will bring new challenges, underpinned by a need to reduce costs, and quickly. Analysis from the Carbon Trust suggests that floating wind can match much of the cost reduction observed in fixed-bottom offshore wind, opening new markets for offshore wind in the process. However, our work has also highlighted several key technology challenges that will need to be overcome to unlock these opportunities and deliver the cost reduction potential proclaimed by industry advocates.

Power of industry collaboration

These challenges require a joined-up effort from government and industry. At the Carbon Trust, we have seen first-hand the benefits of industry collaboration in leveraging public and private funding to accelerate technology development. The



Offshore Wind Accelerator (OWA), now in its tenth year, has played a crucial role in commercialising technology innovations such as 66kV cabling, floating Lidar devices, and new access vessels, all of which have contributed to recent cost reduction and are equally applicable to floating offshore wind.

This model of sharing the cost, the risk — and also the rewards of research and development activities — is now being applied to the floating wind sector, through a joint industry project between the Carbon Trust, Scottish government, and twelve leading international offshore wind developers. The partners share a keen interest in better understanding the challenges and opportunities for commercial-scale floating wind. As such, the Floating Wind Joint Industry Project focuses on unique challenges for large-scale floating wind farms, based on requirements for projects in the hundreds of megawatts to gigawatt capacity, deploying larger next-generation turbines and a range of technology innovations.

Photography | Statoil

Floating Wind Joint Industry Project

A first phase of projects in 2017 covered topics such as floating substations, dynamic cables, mooring systems, and logistics during construction and operation. The findings pointed to a number of areas for further research and development, several of which will be the focus of the next phase of projects throughout 2018.

This includes an evaluation of low-cost methods for undertaking floating-to-floating heavy lift operations, a study to identify cost-effective technologies and strategies for monitoring and inspection, and another to assess the impact of larger turbines (up to 15 MW) on floating foundations.

> We have seen the benefits of industry collaboration in leveraging public and private funding to accelerate technology development

In a similar mould to the role of the OWA in commercialising 66kV cables for the fixed-bottom market, another study will be supporting the development of high-voltage dynamic export cables with ratings of 130-250kV. The lack of suitable dynamic cables to transport power back to shore is a potential bottleneck for large-scale floating wind farms. A common challenge like this is perfect for a collaborative industry approach and could unlock a pipeline of commercial opportunities for those involved.

Looking forward

Our work suggests that there should be no major showstoppers for commercial-scale floating wind farms, but we need a pipeline of commercial projects to validate this, develop the supply chain and reach the volumes of scale necessary to bring down costs. This requires a joined-up effort from government and industry to create a pathway to low cost, low carbon energy generation that will benefit all.

Fixed-bottom offshore wind has proved what can be delivered with the right support in place. Scaling offshore wind to deliver further cost reduction and create new business opportunities will require similar support to develop the technology that can enable penetration of offshore wind in new markets — both fixed and floating.

Experience show that we will all get there quicker by working together.

REVOLUTIONARY: *Above:* The fully installed 30MW Hywind Scotland project; *left:* the original Hywind pilot turbine, off Norway

Offshore wind will play a vital role in the growing Blue Economy

Joao Metelo, chief executive of floating wind designer Principle Power Inc

JOAO METELO

Four years ago, after more than 15 years in onshore renewables, I made the decision to move into offshore wind, which looked to make the same leaps as renewable-energy sources were making onshore. My goal was to make floating offshore wind a large commercial reality globally.

What I've come to find is that I'm not only part of another stage of the renewables revolution. I'm also part of a huge new opportunity that has the potential to reshape the world, and the nations and cities in which we live: the ocean.

Last year, I was invited to participate in the United Nations' Ocean Conference — the first time the UN had ever formally convened to discuss how to conserve and sustainably use the oceans, seas and marine resources for sustainable development (as set out in its Sustainable Development Goal [SDG] 14). While most of the conference participants looked at this SDG from the perspective of mitigating problems and preserving ecosystems, SDG14 also represents a major opportunity for economies and industries globally.

In a world of rising sea levels and changing climate patterns — which have sadly been very much in evidence over the past year — the ocean will no doubt be a key part of our future, both economically and societally. I've come to realise that this economic opportunity can also be a major way in which investment can be brought to bear in tackling the ocean's problems and achieving the goals of SDG14.

The offshore wind sector is a major growth industry in the ocean space, and floating wind will play a major role driving its globalisation and expansion, as well as contributing to the implementation of SDG14 and respective targets. Offshore wind is the renewable-energy source with the highest growth rate expected in the years to come. In fact, over the coming decade, the offshore wind industry is expected to invest on average $30bn per year, which could represent an addition of $1trn to the ocean asset base over the next 25 years. This value can be further reinvested in sustainable activities, coastal communities and conservation efforts. Not many industries can or should be expected to invest at this level, and certainly not in the ocean economy space. (In fact, one of the key problems identified within the ocean community relates to the difficulty of the "Blue Economy" to attract capital.) The offshore wind sector represents a major opportunity for governments, investors, industry, coastal communities and conservation agencies.

I actually see a great similarity between the opportunities today and what I saw 15-20 years ago as onshore renewable energy began its remarkable rise. The true growth potential of the sector was only put into high gear once all key actors realised its capacity to change economies, such as depressed rural communities in deep need of new revenue streams, or local workforces suffering from shuttered manufacturing plants. In many places around the world today, solar and wind represent major sources of local wealth and well-paid jobs. The same exact phenomenon can happen with the Blue Economy.

Throughout my engagement with several Ocean and Blue Economy commitments, I've come to three main conclusions. First, the debate in most forums continues to be focused around mitigation and conservation, when the biggest driver of change is and always will be economics and business. Fostering sustainable economic growth in new sectors should take a lead "change agent" role in this debate.

Second, more industries need to be actively represented in this debate, including established ones such as oil & gas, for instance, and certainly emerging ones such as the growing offshore wind sector, which represents a major new opportunity to bring value to the oceans. Fortunately, we are already witnessing some of this shift as more companies get involved in the space and become active contributors.

And third, there is a major opportunity for new ocean investment activities to jointly work with existing activities, in order to foster growth and sustained value, which can be reinvested into the sustainability of oceans, surrounding communities and ultimately contribute to the achievement of the UN Sustainable Development Goals.

I'm excited to be part of this new sea of opportunity.

FIRST OF MANY: Principle Power's now-decommissioned WindFloat 1 pilot project off the coast of Portugal

Photograph | AFP/Getty

It would be a missed opportunity not to learn from floating oil & gas

EOGHAN QUINN

Eoghan Quinn is global wind lead at engineering firm WorleyParsons Group

PULLING YOUR LEG: Chevron's Big Foot tension-leg patform in the Gulf of Mexico

Photograph | Chevron

Innovation is the lifeblood of any industry. No more true than for the offshore wind sector, which has driven a halving of its levelised cost of energy in the past two years with technological advance. Now, with floating wind it has the opportunity to take this spirit of innovation to the next level and to exercise greater influence on the rapidly evolving global energy system.

Some 80% of Europe's potential offshore wind resource is in waters deeper than 60 metres. This equates to 4,000GW of untapped potential in Europe alone, with — for example — a further 2,450GW in the deep waters off the US, 500GW off Japan and 90GW off Taiwan, according to latest figures from the UK's Carbon Trust. Fixed-based wind is not viable at these depths. Floating is.

Having made the leap from onshore to offshore and now with the prospect of zero-subsidy output in the next five years, the industry is now poised to make this equally significant move forward: the jump from fixed-base to floating.

As with the first shift, this will entail new layers of fiscal, technical, operational and regulatory complexity. It's a tough challenge and one that will call for an unprecedented cross-industrial effort from across the offshore energy and maritime industries. But the rewards would be enormous, given that the vast majority of potential global offshore wind resource streams over waters too deep for traditional bottom-fixed projects.

The coming transition has, in a way, been seen before: in the oil & gas industry's shift to floating structures in the 1970s, a move which opened up new deepwater markets such as the Gulf of Mexico, Latin America and West Africa. Back then it was a high-risk, high-reward strategy. And it worked. It would be a missed opportunity, with the floating wind industry on the cusp of commercialisation, not to tap into the experience gleaned during the evolution of floating structures in oil & gas — the spars, tension-leg platforms (TLPs), and even new low-motion FPSOs (floating production storage and offloading units, and the lessons learnt in managing the complexities of designing, building, operating and maintaining assets in these highly complex offshore environments.

Other sectors will also be key in speeding floating wind into full industrialisation. As firms start to move their technologies from sea trials and pilot arrays to utility-scale wind farms, they will need specialist expertise from the existing maritime and offshore energy sectors to de-risk and optimise their designs for the full project lifecycle. This will entail challenges that are technical — such as developing dynamic power cables that can survive harsh offshore environments or designing floating foundations and mooring turbines to the seabed; regulatory — such as the US's Jones Act, which prevents developers from sourcing vessels from abroad, pushing up prices; and operational — the very likely constraints around vessel availability and difficulties in servicing floating arrays efficiently.

> The coming transition has, in a way, been seen before: in the oil & gas industry's shift to floating structures in the 1970s

And floating wind power can be helped by other new energy sectors, such as wave and tidal, where there have been technological advances in synthetic mooring lines, for instance, that might be further developed for use on still more cost-efficient future projects.

The future for floating is brightened by its flexibility. The first 500MW floating wind farms are not far off, but the technology is also ideal for remote production for islands — and even as "energy transition" projects at ageing offshore oil and gas fields, for which we are developing a floating wind concept that has low-motion response comparable to TLP and spar-based designs in water depths of 70 metres or more.

Floating wind offers huge global clean-energy potential and projects are getting bigger and more multifaceted. But these complex, deep offshore environments will require robust technology, strong onshore infrastructure and the right expertise to ensure success. By partnering with companies in this space, the sector can unlock that complexity and begin