Offshore Wind Testbeds

European Experience

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Offshore Wind Testbeds

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Final Report

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Notice

Abstract

This study supplements a collection of studies prepared on behalf of the New York State Energy Research and Development Authority (NYSERDA) to provide information related to a variety of environmental, social, economic, regulatory, and infrastructure-related issues implicated in planning for future offshore wind energy development off the coast of New York State. This report contains a summary of the European offshore wind projects that have set aside specific testbeds for the testing and demonstration of new technology. Due to the increasing scale and ongoing deployment of offshore wind projects within Europe, natural incremental technology development and deployment have been possible, such that commercial-scale projects constructed in the early 2000s have delivered knowledge and experience benefits that have led to significant cost and risk reductions. However, step changes in deployed technology have typically been preceded by testing and demonstration prior to full-scale deployment, and much of this testing has been undertaken at specifically leased demonstration sites. NYSERDA's intent is to facilitate the principled planning of future offshore development, to provide a resource for the various stakeholders, and to support the achievement of the State's offshore wind energy goals.

Keywords

offshore wind, testbed, research and development, technology, demonstration

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Executive Summary

This report contains a summary of the European Offshore Wind (OSW) projects that have set aside specific testbeds for the testing and demonstration of new technology. The report intends to help inform New York State in determining the potential for adding a testbed to a NYS project OSW site. Case studies from different European markets in which government agencies have promoted offshore testbeds are included, illustrating different approaches to operating the facilities.

The global offshore wind market has been asking for opportunities to develop offshore test projects. Offshore test facilities can potentially reduce production costs of electricity from offshore wind farms, and therefore keep offshore wind energy competitive.

Due to the increasing scale and ongoing deployment of offshore wind projects within Europe, natural incremental technology development and deployment have been possible, such that commercial-scale projects constructed in the early 2000s have delivered knowledge and experience benefits that have led to significant cost and risk reductions. However, step changes in deployed technology have typically been preceded by testing and demonstration prior to full-scale deployment.

The following is a breakdown of the 24 identified offshore wind projects developed or delivered with a technology development or testing objective that have either been awarded consent, delivered, or decommissioned:

- Sixteen use ground-fixed foundations, while eight are floating offshore wind demonstrators; and
- Twenty have been used or developed specifically to test wind turbine foundation technology (including floating structures), nine have been used to test wind turbine technology, and only three (most recently) to test electrical system technology, with some projects testing multiple technologies.[1]

Although owners have been willing to undertake incremental technology development on a project-by-project basis where there is an economic driver or technical requirement to do so, it has been very rare for owners to integrate strategically directed wind turbine foundation technology, testing, and development, or other testing which imposes significant risks or costs onto commercial-scale projects. This document does not seek to identify all testing of new technology undertaken on commercial sites, although specific projects of interest have been highlighted.

There is one known instance of an owner delivering a novel wind turbine foundation with the intention of applying the technology across another project in its portfolio: Ørsted's (formerly DONG Energy's) installation of a single steel jacket with suction buckets at Borkum Riffgrund I (in Germany), subsequently to be widely applied at Borkum Riffgrund II.

Much other testing has been undertaken at specifically leased demonstration sites, either with testing and demonstration scope enveloped prior to bidding by the leasing authority (e.g., The Crown Estate in the UK) or defined by the bidder as part of the bidding process, where bids are typically scored against, at least, some qualitative criteria. Often, a level of financial support is tied to the leases or is applied for from research and development funds. A slight adaptation of this exists in Germany where projects have been able to apply for extra grid capacity from the German authorities, although without accompanying financial support.

The principle of leasing authorities identifying and leasing sites for specific testing purposes remains in place and has been adopted for recent demonstration site tenders, for example at Nissum Brednings in Denmark and Borssele V in the Netherlands.

There are some exceptions to this. For example, in the UK the National Renewable Energy Centre (NaREC) consented a wide envelope of technical concepts at Blyth before selling the lease and consent rights to EDF, an electric company in France. However, the principle of defining test and demonstration purposes as part of lease agreements is still the accepted practice.

The relative importance of funding should not be understated, as owners and developers are often reticent to spend significant sums at risk, even for targeted research and development activities. It can be assumed that such projects must meet the same financial hurdles as full-scale commercial projects.

With test and demonstration projects typically being run by their owners as commercial projects, a key challenge for the leasing authority and regulator is ensuring that maximum value is gained through the provision of research and development funding, and that the knowledge and experience gained from testing and development is not unduly monopolized.

1 Introduction

This report emphasizes the importance of the slogan “test and learn” in reference to understanding and forecasting the performance reliability of new technology before full-commercial operation. Testing a new technology is the only way to minimize uncertainty, build market confidence, and reduce the levelized cost of energy for offshore wind.

Neither this study, nor the New York State Offshore Wind Master Plan, or its collection of studies, commit NYSERDA or any other agency or entity to any specific course of action with respect to the development of offshore wind projects within the offshore study area (OSA). Rather, NYSERDA's intent is to facilitate the principled planning of future offshore development, to provide a resource for the various stakeholders, and to support the achievement of the State’s offshore wind energy goals. As such, this report is considered supplemental to the Master Plan and has been provided to aid decision making by state and federal agencies as well as project sponsors themselves.Around the world, testbed facilities have been used for conducting controlled testing of technologies to support projects through all stages of development from prototype to full-scale demonstration projects, helping to tackle the technical, logistical, and commercial challenges.

This report focusses on testbed facilities in Europe, as its well-developed offshore wind industry offers the majority of examples compared to most areas of the world. The report deals only with the offshore testbed facilities. The following are the four types of facilities recognized:

- On-shore innovation and research centers. These often comprise rigs for accelerated lifetime testing of components, fatigue testing, or controlled replication of harsh marine conditions.
- On-shore turbine test facilities. Here full-scale offshore wind turbines are tested, often at shoreside locations but with full accessibility to monitor performance and change components.
- Offshore test facilities. Specialist locations dedicated to the testing of turbines, foundations, or technologies, located fully offshore, but often relatively close to logistical centers.
- Offshore wind test locations. Dedicated positions within commercial windfarms that have been reserved for testing new technologies or new methods.

Table 1 provides a list of worldwide offshore wind test facilities for fixed foundations, grouped by Europe, Asia, and North America regions.

Table 1. Offshore Wind Demonstration Projects—Fixed Foundations

Source: RCG Global Renewable Infrastructure Projects database

Project	Purpose	Capacity (MW)	Country	Status
EUROPE				
Operational and part of commercial project				
Belwind Demo	Jacket foundation	6	Belgium	Operational
Borkum Riffgrund 1 (SBJ)	Suction bucket jacket foundation	4	Germany	Operational
Gunfleet Sands III	Prove next-generation turbine	12	England	Operational
Not operational and part of a commercial project				
Deutsche Bucht ("DeBu") (Demo locations)	Suction bucket monopile foundation	16	Germany	Pre- construction
Operational (including decommissioned) and not part of a commercial project				
Alpha Ventus 1	Jacket foundation	30	Germany	Operational
Alpha Ventus 2	Tripod foundation	30	Germany	Operational
Beatrice Demonstrator	Jacket foundation	10	Scotland	Operational
Blyth Offshore	Prove offshore turbine	4	England	Operational
Levenmouth demo turbine (Fife Energy Park)	Prove turbine concept	7	Scotland	Operational
Lely	Monopile foundation	2	Netherlands	Decommissioned
Tahkoluoto Demo	Gravity base, local conditions	42	Finland	Operational
Not operational and not part of a commercial project				
Blyth Offshore Wind Demonstrator (formerly Test Site 1)	Concrete gravity base foundations	42	England	Construction
Blyth Offshore Wind Test Site 2	unknown	29	England	Consented
Blyth Offshore Wind Test Site 3	unknown	29	England	Consented
EOWDC (Aberdeen Bay)	Suction bucket jackets, HV array cables.	92	Scotland	Construction
Forthwind Offshore Wind Demonstration Array	Jacket	47	Scotland	Scoping
Forthwind Offshore Wind Demonstration Project	Jacket	18	Scotland	Consented
Frederikshavn Demo	unknown	48	Denmark	Dormant
MetCentre Demo (Mingyang)	Jacket foundation	6	Norway	Consented
Nissum Brednings Vindmøllelaug Demo	Gravity jacket foundations, latest turbine, HV array cables.	28	Denmark	Construction
ASIA				
Choshi Offshore Demo	Gravity foundation, prove turbine type	2	Japan	Operational
Formosa Demo	Local experience	8	Taiwan	Operational
Fuhai I - Changhua Offshore Pilot Project (COPP)	Local experience	10	Taiwan	Consented
Fuqing Xinghua Gulf Demo (CSIC)	Local experience, prove turbine type	10	China	Pre-Construction
Fuqing Xinghua Gulf Demo (Dongfang)	Local experience, prove turbine type	5	China	Pre-Construction
Fuqing Xinghua Gulf Demo (GE)	Local experience, prove turbine type	18	China	Pre-Construction
Fuqing Xinghua Gulf Demo (Goldwind)	Local experience, prove turbine type	13	China	Pre-Construction
Fuqing Xinghua Gulf Demo (Mingyang)	Local experience, prove turbine type	13	China	Pre-Construction
Fuqing Xinghua Gulf Demo (SE)	Local experience, prove turbine type	12	China	Pre-Construction
Fuqing Xinghua Gulf Demo (THI)	Local experience, prove turbine type	10	China	Pre-Construction
Guangdong Zhuhai Guishan Demo (Jacket)	Jacket foundation	87	China	Pre-Construction
Guangdong Zhuhai Guishan Demo (Monopile)	Monopile foundation	102	China	Pre-Construction

Table 1 continued

Project	Purpose	Capacity (MW)	Country	Status
Gujarat Demo		100	India	Development
Jiangsu Rudong Intertidal Demo		32	China	Operational
Jiangsu Rudong Intertidal Demo Extension 1.1	Monopile	100	China	Pre-Construction
Jiangsu Rudong Intertidal Demo Extension 1.2	Tripod	100	China	Pre-Construction
Kitakyushu Offshore Demo	Hybrid gravity jacket foundation	2	Japan	Operational
Miaoli County Demo		0	Taiwan	Development
Setana Nearshore	High-rise pile cap	1	Japan	Operational
NORTH AMERICA				
Block Island	Jacket foundation	30	USA	Operational
Virginia Coastal Wind (VCW) Demo	Jacket foundation	12	USA	Development
GOWind Demo	Jacket foundation	18	USA	Abandoned
Icebreaker (Lake Erie)	Suction bucket foundations	21	USA	Development
New Jersey (Atlantic City Demo)	Jacket foundation	24	USA	Dormant

2 European Testbed Experience

Project owners have been willing to undertake incremental technology development on a project-by-project basis where there is an economic driver or technical requirement to do so. However, it has been rare for owners to integrate strategically directed testing and development for wind turbine foundation technology, or other testing which imposes significant risks or costs, onto commercial-scale projects.

2.1 Testbed Uses

The role of offshore wind test sites is to enable owners and developers to undertake research and development activity that they are unwilling to do on commercial projects. This document does not seek to identify all testing of new technology undertaken on commercial sites, although specific projects of interest have been highlighted.

Offshore wind test sites have often been developed to test wind turbine foundation technology, although specific wind turbine test sites have been created. Owners often integrate testing of wind turbine technology and other technology (including electrical systems) in sites assigned for wind turbine foundation testing.

Most European test facilities have been specifically developed and delivered as "demonstration sites," which are constructed as a trial run for the operation of one or more new technologies. They tend to be relatively small in scale when compared to commercial offshore wind projects.

It is expected that owners and developers will judge the financial merits of demonstration sites against commercial-scale projects, so typically additional funding is required to ensure the project is able to proceed through the development, procurement and construction processes. This funding may take a variety of forms, such as:

- Enhanced Renewable Obligation Certificate (ROC) rights (e.g., UK)
- Preferential Feed-in-Tariff rates (e.g., Denmark)
- European Union (EU) grants and other capital funding

A list of the European test sites along with descriptions of key aspects and test objectives are presented in Table 2 for fixed foundation concepts (for information on concepts regarding floating foundations see appendix A). The table and Figure 1 specifically include whether the test location is a demonstration site or related to a commercial-scale project as well as the technology the site is capable of testing.

Table 2. Offshore Wind Demonstration Projects—Fixed Foundations

Source: RCG Global Renewable Infrastructure Projects database

Test site	Ownership	Status	Delivery route	Year operational	Technology tested / to be tested	WTG capacity	Commercial project capacity	Testbed project capacity	Comments
Operational and part of commercial project									
Belwind Demo	GE Power (50%) Lydian (50%)	Operational	Demonstration Testbed is adjacent to Belwind II project. Collaboration between Alstom and Belwind II.	2014	1 x Alstom Halilade 150 wind turbine (6 MW)	6 MW	165 MW	6 MW	Installed on a steel jacket within Belwind II project, comprising 55 x Vestas V90 wind turbines (3 MW) (remaining wind turbines installed on monopiles)
Borkum Riffgrund 1 (SBJ)	Ørsted A/S (50%) Kirkbi A/S (32%) Oticon Foundation (18%)	Operational	Testbed within Borkum Riffgrund I project	2014	Single tripod jacket with suction bucket foundation (SBJ = suction bucket jacket)	4 MW	308 MW	4 MW	Suction bucket jacket foundation tested with Siemens SWT 4.0-120 wind turbine (4.0 MW). It is expected that Borkum Riffgrund II (located adjacent to Borkum Riffgrund I) shall comprise 20 such foundations, expected to be commissioned in 2019.
Gunfleet Sands III	Ørsted A/S (100%)	Operational	Demonstration Testbed is extension to Gunfleet Sands I and II wind farms, specifically for wind turbine testing	2013	2 x Siemens SWT-6.0-120 (6 MW)	6 MW	172.8 MW	12 MW	Extension to existing site, to test 6 MW wind turbine (with shorter blades).
Not operational and part of a commercial project									
Deutsche Bucht ("DeBu") Offshore Wind Farm (Demo locations)	Northland Power Inc. (100%)	Under Construction	Testbed within 252 MW DeBu project	2019	2 x suction bucket with MHI Vestas V164-8.4 wind turbines	8.4 MW	252 MW	16.8 MW	Additional grid capacity awarded to project to test Universal Foundation mono-bucket foundations concept, coupled with MHI Vesta's latest turbine technology.
Operational (including decommissioned) and not part of a commercial project									
Lely	Vattenfall AB (100%)	Decommissioned	Demonstration	1994	4 x Nedwind 500 kW wind turbines	0.5 MW	-	2 MW	The project uses monopile foundations. The site was decommissioned in 2016.

Table 2 continued

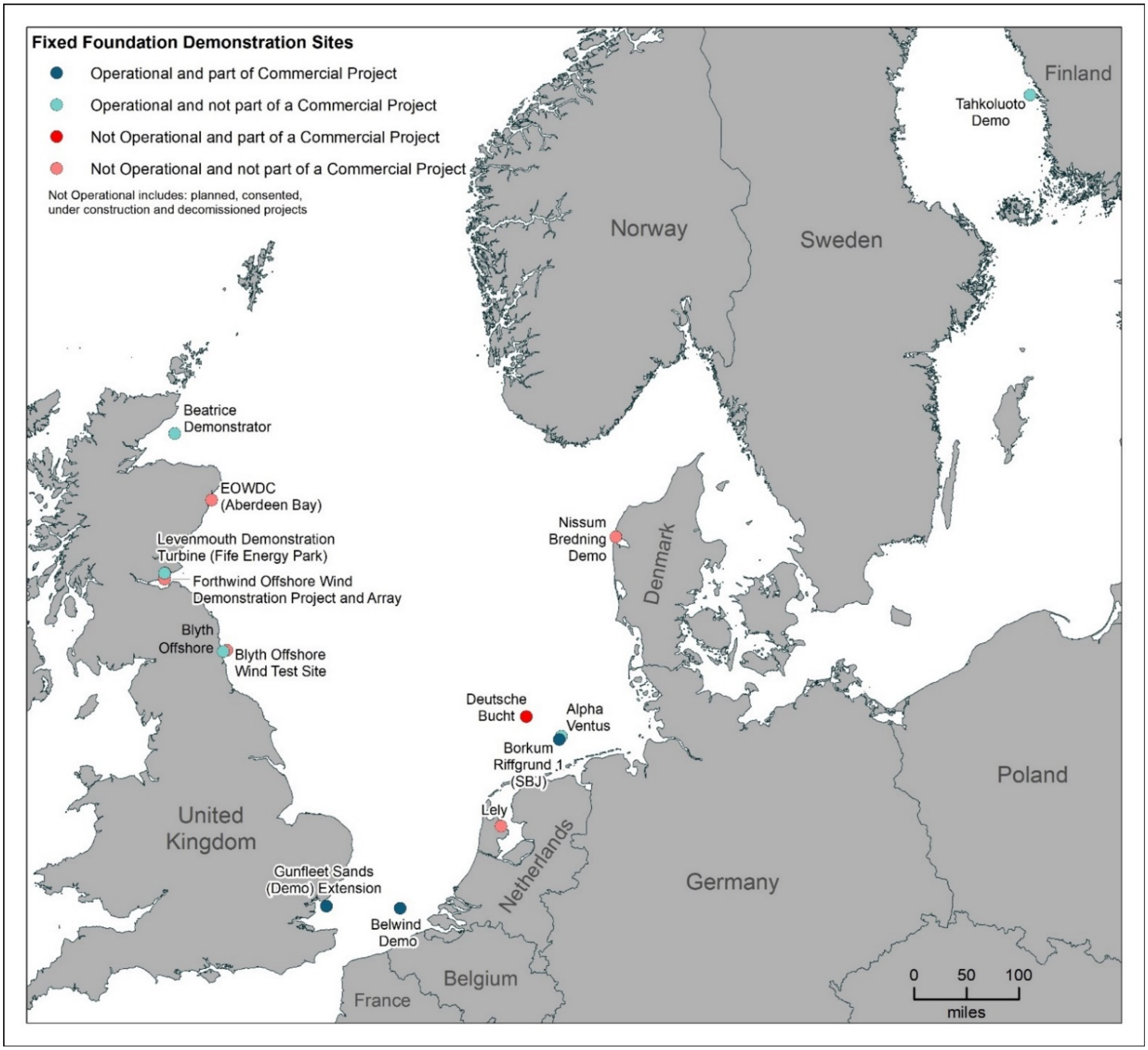
Test site	Ownership	Status	Delivery route	Year operational	Technology tested / to be tested	WTG capacity	Commercial project capacity	Testbed project capacity	Comments
Blyth Offshore	E.ON Climate & Renewables GmbH (100%)	Operational	Demonstration	2000	2 x Vestas V80 (2 MW) installed on monopile foundations	2 MW	-	4 MW	Delivered by consortium including E.ON, Shell, NUON and Border Wind. Project was intended to demonstrate offshore wind turbine installation was possible in North Sea conditions
Beatrice Demonstrator	SSE Plc (SSE) (50%) Talisman Energy (UK) Limited (50%)	Operational	Demonstration	2007	2 x Steel Jacket Foundations with REPower 5M (now Senvion)	5 MW	-	10 MW	The electricity generated is fed to the Beatrice Alpha oil platform, located nearby. The project was intended to demonstrate installation was possible in deeper waters (of approximately 45m).
Alpha Ventus	EWE AG (48%) E.ON SE (26%) Vattenfall AB (26%)	Operational	Demonstration	2008	6 x Steel Jacket Foundations with REPower 5M (now Senvion) 6 x Tripod Foundation with Multibrid M5000 (now Areva)	5 MW	-	60 MW	Demonstration project is unique in testing two wind turbine models on two distinct foundation concepts (jackets and tripods). Project-specific transmission link to onshore substation, including offshore substation.
Levenmouth demonstration turbine (Fife Energy Park)	Offshore Renewable Energy Catapult (100%)	Operational	Demonstration	2013	1 x Samsung 7 MW wind turbine	7 MW	-	7 MW	Recently purchased from Samsung Heavy Industries by Offshore Renewable Energy (ORE) Catapult, a government funded R&D accelerator programme.
Tahkoluoto Demo	Suomen Hyotytuuli Oy (100%)	Operational	Demonstration	2017	10 x Siemens SWT-4.0-130 wind turbines (4 MW)	4 MW	-	40 MW	First Finnish offshore wind farm project, developing experience in Finnish market
Not operational and not part of a commercial project									
Nissum Brednings Vindmøllelaug Demo	Nissum Brednings Vindmøllelaug (100%)	Under Construction	Demonstration	Under Construction	4 x Siemens SWT-7.0-154 wind turbine (7 MW) installed on hybrid gravity-jacket foundation (with concrete base and transition piece). 66 kV array cables	7 MW	-	28 MW	Site serving as a testbed for Siemens wind turbine and 66 kV electrical technology. Using gravity-jacket foundations.

Table 2 continued

Test site	Ownership	Status	Delivery route	Year operational	Technology tested / to be tested	WTG capacity	Commercial project capacity	Testbed project capacity	Comments
EOWDC (Aberdeen Bay)	Vattenfall AB (100%)	Under Construction	Demonstration	Under Construction	11 x jackets with suction buckets with MHI Vestas V164-8.4 wind turbines (8.4 MW). 66 kV array cables.	8.4 MW	-	92.4 MW	Project suffered delays during consenting. Now being delivered to test jackets with suction buckets, as well as 66 kV array cables.
Blyth Offshore Wind Demonstrator (Test Site 1)	EDF Energy Renewables (50%) EDF Energy Nouvelles Group (50%)	Under Construction	Demonstration	Under Construction	5 x Concrete Gravity Base Structures (CGBS) with MHI Vestas V164-8.3 (8.3 MW). 66 kV intra-array cables.	8.3 MW	-	41.5 MW	Site consented by National Renewable Energy Centre (NaREC) as 15 wind turbine test site (in same consent as Blyth Offshore Wind Test Sites 2 and 3). Site acquired by EDF following consent award. Project using gravity-based foundations and 66 kV array cable
Blyth Offshore Wind Test Sites 2 and 3	EDF Energy Renewables (50%) EDF Energy Nouvelles Group (50%)	Consented	Demonstration	N/A	Not known. Consent allows for monopile, piled jacket and jacket with suction bucket foundation types and maximum wind turbine rotor diameter of 170m.	N/A	-	83 MW	Consented with above. No public information on timeframe for further testing.
Frederikshavn Demo	EDF Energy Nouvelles Group (100%)	Dormant	Demonstration	N/A	The site was intended to be used to test Vestas V164-8.0 wind turbine (8 MW)	N/A	-		DONG Energy (Ørsted) divested the site to EDF in 2015, stating that its testing requirements were being met elsewhere. No current plans for site are known.
Forthwind Offshore Wind Demonstration Project	2-B Energy (100%)	Consented	Demonstration	N/A	2 x 2-B 6 MW wind turbines (WTGs include integrated steel lattice tower/foundation)	N/A	-	12 MW	2-B wind turbine has a novel integrated tower and foundation lattice structure design

Figure 1. Location Map of European Demonstration Sites—Fixed Foundation

Source: RCG



2.2 Turbine Testing

The growth in wind turbine capacity, driven by economic fundamentals and the need to reduce offshore wind costs, has been significant over the last 20 years. Wind turbines are typically subject to a certification process, which tends to provide greater certainty in performance over, for example, a new and untested foundation concept, particularly if the drive-train technology has been proven in previous (smaller) models.

Wind turbine testing in the offshore environment has typically been undertaken by both wind turbine suppliers and project owners where there is a perceived need (e.g., for a new drive-train concept). Wind turbine suppliers have used offshore testing to gain construction and operational understanding of the wind turbines, drive design and operating cost reduction and certainty, as well as to display their products, while project owners typically seek to reduce project and investment risk.

Of the key offshore wind turbine models currently on the market in Europe, the MHI Vestas V164 (8 MW to 9.5 MW variants) and Siemens SWT-7.0-154 (7 MW variant) are currently installed or are in construction on demonstration sites. These models share the drive-train concept with operational models, which may be caused more by a desire to increase returns of the demonstration sites than by the need to test the technology. Although there are a number of competitors to MHI Vestas and Siemens (now SiemensGamesa), since the construction of the Beatrice Demonstrator (2007) and Alpha Ventus (2008), only Alstom (now GE Renewable Energy) has tested its wind turbine at a demonstration site (adjacent to Belwind II). Samsung installed a prototype 7 MW wind turbine at Levenmouth (Methil) in Scotland, which was adjacent to the shoreline and has since been acquired by ORE Catapult.

2.3 Foundation Testing

Although monopiles were initially tested at the Lely project in the 1990s and at Blyth in the United Kingdom (UK) in 2000, key experience in the design and operation of monopile foundations has been acquired through commercial project deployment, and in particular through two rounds of leasing in the UK since the early 2000s. Key industry lessons in grouted connection design and fatigue design, driven by known short-comings in design methodologies, were developed from this experience, which in turn led to incremental improvements, validated through cross-industry research and development initiatives.

Piled steel jackets, which are an alternative concept to monopiles typically used in water depths of greater than 35 m to 40 m, have been tested at Beatrice (2007) and at Alpha Ventus (2008) and have been used in many commercial-scale projects since. The tripod concept has not had significant traction in the offshore wind market beyond Global Tech I and Borkum West II (which received some EU capital funding for the construction of the tripod foundations[2]).

With the drive towards reducing the cost of energy while developing in deeper water, further foundation concept testing has been undertaken and a number of jacket concept modifications have been developed. Those installed at demonstration sites are as follows:

- A single-steel tripod jacket with suction buckets—selected to be tested by DONG Energy (Ørsted) at Borkum Riffgrund I and subsequently to be installed at commercial scale at Borkum Riffgrund II).
- Steel jacket with concrete gravity-base foundation and transition piece at Nissum Bredning Demonstration project, selected by the project owners who won the site in a competitive auction, and due to be in operation in 2018. At least one other similar concept has been tested in Japan.

EDF has installed five concrete gravity-base structures (CGBS) at the Blyth Demonstration site in the UK, along with commercial-scale wind turbines, although it should be noted that other commercial-scale projects have previously deployed gravity-base foundations (notably Nysted and Thornton Bank, which again secured some EU capital funding). EDF subsequently defined the project and decided on the installation of concrete gravity-base structures to assess the technology prior to potentially major deployments in their French sector projects.

It should be noted that knowledge and experience of certain technologies reside with the owners and contractors and may not therefore be in the public domain. This is the case with suction bucket jacket foundations, which have been under trial by Ørsted—a company that typically retains design responsibility on its projects—and are intended for the 450 MW Borkum Riffgrund II project. It would be a challenge for other developers and owners to utilize the same technology to deliver potential cost savings without access to Ørsted's design and operational experience.

Foundation technologies are typically driven by site-specific conditions, including water depth and geotechnical conditions, and therefore the potential for applying technologies directly to the New York State market is conditional on applicability of conditions. It would be appropriate to understand the similarities between New York State ground conditions and those in Europe, and therefore the opportunity to learn directly from the European market or to add specific value based on particular local challenges.

2.4 Other Testing

In the last few years, as the industry has moved towards higher array cable voltages as a measure to reduce energy losses, some testing of 66-kV cables and equipment has been undertaken. In each case, the selection has been done by the project owners and may be driven by commercial project realities, or by a need (e.g., in the lease constraints) to test novel technology. The technology is likely to be transferrable to the U.S. market, as knowledge and experience will be retained by the suppliers.

Although not specifically included in Table 2 and Figure 1, offshore meteorological measuring for mast installations in the UK have been used as testbeds for novel foundation concept testing and development. Notably the following two foundation concepts have been tested during the UK Round 3 development process:

- Monopile and suction bucket foundation (design: Universal Foundation) installed by the Forewind consortium at Dogger Bank, UK.
- Twisted jacket foundation (design: Keystone Engineering Inc.) installed by Mainstream Renewable Power at Hornsea, UK.

Installation and operational experience of these concepts has not resulted in wide market take-up at present. Full-scale testing and demonstration of these concepts supporting wind turbines would be required to further demonstrate the technology, as design requirements are fundamentally different for wind turbine operation.

3 Processes for European Testbeds

The global offshore wind market has been asking for opportunities to develop offshore test projects. Offshore test facilities can potentially reduce the levelized costs of energy from offshore wind farms, and therefore, keep offshore wind energy competitive.

This section presents four case studies from different European markets where government agencies have promoted offshore testbed facilities. The case studies are the following:

- Netherlands—Borssele Wind Farm Site V
- Denmark—Energy agreement offshore test projects
- Germany—Connection capacity for pilot wind turbines
- United Kingdom—Crown Estate Demonstration Lease Round

The Netherlands' tender for an innovation site is currently live. In the other examples, a brief description of the winning bid(s) is provided to illustrate the types of schemes that have been selected.

A common theme from the processes focuses on technology that is near market with a goal of accelerating the introduction of new equipment or techniques that will reduce costs in the near-term (rather than assisting research and development efforts). A second goal is to give local supply chains exposure to leading-edge technologies and techniques.

3.1 Innovation Site: Borssele Wind Farm Site V

In 2013, the Netherlands Enterprise Agency (rvo.nl), an executive agency of the Dutch government, set up a program called SDE+ in order to meet the government's targeted increase in domestic offshore wind capacity from 1 GW to 4.5 GW under its approved Energy Agreement. As a result, the Borssele Wind Farm Zone was created.

The Borssele Wind Farm Zone in the Netherlands' North Sea comprises four large sites, collectively with a capacity of around 1380 MW due to be delivered by 2020, and one smaller site (nominally with 20 MW) designated as the "innovation site." Each of these sites were granted to developers via a competitive auction process run by the Netherlands Enterprise Agency. Sites I and II (700 MW) have been awarded to Ørsted Borssele 1 B.V. Sites III and IV (680 MW) have been awarded to Blauwwind II c.v., a consortium of Eneco, Diamond Generating Europe (a 100% subsidiary of Mitsubishi Corporation), Shell and Van Oord.

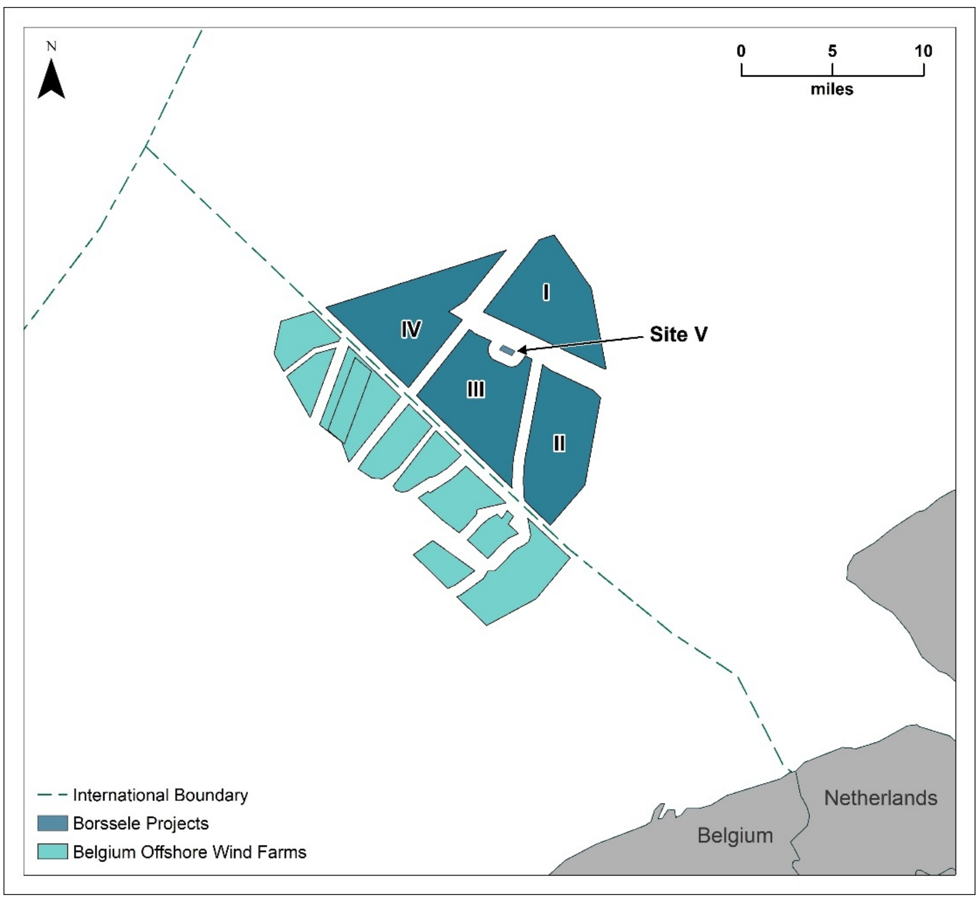
Site V is a small site that is mainly situated within Site III of the Borssele Wind Farm Zone.[3] The processes for selecting the operator of the demonstration site was ongoing when this report was published.

For site V, the government of the Netherlands aims were to achieve the following:

- Demonstrate: Create an opportunity for operators to demonstrate almost fully-developed technologies for actual market introduction.
- Cost reduction: Contributing towards offshore wind cost reductions.
- Local economy: Expand the market and export potential for Dutch companies.
- Knowledge sharing: Building knowledge in the Netherlands by involving local SMEs and technical institutions.

Figure 2. Location Map of Borssele Wind Farm Zone

Source: RCG



The government of the Netherlands recognizes that demonstrating new technologies is more expensive than rolling out existing technologies and is therefore providing a subsidy for the additional investment costs (Borssele III and IV). Conveniently located near the future TenneT Borssele Beta offshore converter station, site V's grid connection costs are minimal by design with only a single 3-km collector cable connected directly to the infrastructure.

The Netherlands Ministry for Economic Affairs launched a tender for the innovation zone; the tender opened on January 2, 2018, and closed on January 18, with the result announced on April 19, 2018. The winning bid was assessed based on the following four qualitative criteria:

- Contribution to cost reduction of offshore wind energy (which must be quantifiable, but can include improvements to an operator's business case, e.g., through reduced risk premiums).
- Contribution to the Dutch economy (which must also be substantiated).
- Degree of innovation relative to the state of the art from an international point of view and the degree to which the Dutch knowledge position is boosted.
- Quality of the project (approach and methodology, risk management, feasibility, participating parties, effectiveness and efficiency of the resources deployed).

In addition, the government made it clear that the subsidy was investment aid and not for research and development. The selected technology was considered sufficiently advanced and close to being used by an operator in an operational environment. This means that the equipment must be at technology readiness levels (TRL) 7-9. In addition, the facility had to be commissioned within four years, but production could start as early as August 2020 (when the offshore grid infrastructure is scheduled to be completed). The participation of Dutch SMEs receives a positive weighting.

The subsidy was granted to the winning bid on the basis of the bidding company's status as a "producer of renewable electricity using offshore wind energy." The subsidy for site V is capped at EUR 59 m (c. USD 73 m), which breaks down into an investment subsidy of up to EUR 15 m (c. USD 19 m) and a 15-year operating subsidy (per kWh) of up to EUR 44 m (c. USD 55 m). The investment subsidy is capped at 45% of the additional costs compared with the adjacent Borssele III benchmark. It is paid in advance, subject to compliance of agreed project milestones. The operating subsidy follows the same rules as other sites in recent Netherlands tenders. The process allowed the subsidy to be uplifted if small- and medium-sized enterprises were involved.

Bids were ranked by a committee of independent experts. The tender required bidders to meet certain financial hurdles to ensure bids were viable, including substantial guarantees. In the event of several applications ranking equally, the bid with the lowest investment was awarded the subsidy. The operating subsidy is set to a maximum of EUR 0.05449/kWh (USD 0.07/kWh). Unlike the earlier Borssele tenders, the tender amount is not a ranking criterion.

On April 6, 2018, Minister Wiebes of the Netherlands Department of Economic Affairs and Climate announced that Two Towers B.V., a consortium of Van Oord Renewable Finance, Investri Offshore and Green Giraffe Holding, won the tender for Borssele Wind Farm Site V.[4]

The principal innovations to be tested are an innovative mounting system between the tower and the foundation, expected to enable wind turbines to last longer and require less maintenance; an improved coating that protects the turbines more effectively while enhancing their cost-efficiency; and testing of the promotion of oyster beds around the site to prevent erosion of the sea floor around the wind turbine foundations and aid in the recovery of the marine ecosystem.

The Two Towers B.V. consortium will receive an innovation subsidy of up to EUR 15 m (USD 17 m) for the purpose of testing the proposed innovations. It will receive an additional subsidy of EUR 35 m (USD 40.6 m) in exchange for the electricity supplied.

3.2 Denmark’s Energy Agreement Offshore Test Projects

Example: Nissum Brednings Vindmøllelaug Demo

As part of its 2012 Energy Agreement, the Danish government has established a support scheme for offshore test projects with a capacity of up to 50 MW. This was aimed as a supplement to the many existing onshore test facilities to provide the final step in development of a new turbine or new components for a turbine.

In July 2015 the Danish Energy Agency published a call for applications for tests of new technologies to establish and operate wind energy production offshore. The applicants had to comply with a number of minimum assessment criteria, such as the technical and financial capacity, to ensure delivery from a development and commercial perspective. Turbines in the test scheme will receive a subsidy per kWh for a production period corresponding to about 50,000 full-load hours, and then only market price until decommissioning.

The scheme had a special emphasis, focusing on the testing facility's potential ability to significantly reduce electrical production costs from offshore wind turbines. Applications were assessed against the following technical criteria:

- Innovation. The project must address an innovative technological development compared with existing technologies and solutions.
- Technically feasible. The test is well-defined and technically feasible.
- Full-scale. Aid will not be provided for tests in the research phase or tests which are not fully scalable.

In addition, the test project had to have a clear commercial perspective, capable of moving into a commercial phase once initial testing was completed. Therefore, applications had to satisfy the following elements:

- Demand. The test meets a demand in the market and has a well-defined customer aim.
- Growth potential. There is an economic growth potential and prospect of a competitive product.
- Verification. The test enables certification or some other relevant type of verification.
- Diversity. The more technologies to be tested, the more the project will be assumed to promote the long-term commercial perspective.

Four projects were shortlisted and assessed based on the above criteria by both the Danish Energy Agency and selected external evaluators. A proposal by Nissum Brednings Vindmøllelaug was selected as the winning application. The aid was granted in February 2016 and the commitment finalized in June 2016.

3.2.1 Nissum Brednings Vindmøllelaug—Testbed for Integrated New Technologies

I/S Nissum Brednings Vindmøllelaug (NBV) applied in collaboration with Jysk Energi A.m.b.a. and Siemens Wind Power A/S for a 28 MW project called "Testbed for new technologies and integrated design."[5]

SiemensGamesa will supply four 7-MW direct drive wind turbines and an innovative gravity jacket foundation solution has recently been installed. The project will be connected to the grid using Siemens' new 66-kV voltage grid connection solution, including a new transformer, cable, and switchgear systems. The higher voltage results in lower costs for cabling, and lower losses. Further innovations such as controller settings will be tested.

The project will test a new gravity jacket foundation concept, which allows the construction of the foundations at lower cost than for monopiles. Savings in steel will be provided by the slender tower concept using prototypes of a new lightweight turbine tower especially suited to jacket foundations.

The NBV offshore wind farm will be supported by a guaranteed feed-in tariff of DKK 0.7/ kWh (USD 0.129/kWh) for the initial 10 years, expected to equate to 50,000 full-load hours of operation. Construction is underway, and commissioning will be completed in 2018.

3.3 Germany's Connection Capacity for Pilot Wind Turbines

Example**:** Deutsche Bucht ("DeBu") Offshore Wind Farm (Demo locations)

The German Energy Industry Act (*Energiewirtschaftsgesetz*—EnWG) contained provision for operators to apply for offshore wind demonstration sites. The projects needed to be extensions to existing schemes and allowed for up to 50 MW of capacity to be added to existing or commissioned offshore connections, providing appropriate capacities were available.[6]

Deutsche Bucht ("DeBu") Offshore Wind Farm (Demo locations)—mono-bucket foundations

In 2016, the 252-MW Deutsche Bucht (DeBu) project was allocated extra grid capacity by the German authorities to demonstrate state-of-the-art technology as part of the *Anschlusskapazität für Pilotwindenergieanlagen auf See* (connection capacity for pilot wind turbines at sea) project.[7] DeBu is located in the German North Sea Exclusive Economic Zone, approximately 95 km northwest of the island of Borkum and will be connected to the 800 MW BorWin Beta offshore converter station, which has already been constructed.

Northland Power, the owner of the project, plans to install two MHI Vestas 8.4-MW turbines onto mono-bucket foundations to test the suction bucket foundation technology. This will be the first industrial-scale version of Universal Foundations' suction bucket foundation. Installation offshore is expected in spring 2019. The project receives funding from the EU's DemoWind demonstrator scheme, a research and development funding scheme set up by those European countries with developing offshore industries.

The Universal Foundation mono-bucket concept has been in development since 2001 via prototypes including a 3-MW turbine unit in Frederikshavn, Denmark, and meteorological mast installations at projects including the UK's Dogger Bank and Horns Rev 2 in Denmark.

Figure 3. Suction-bucket Foundations Used for Met Masts on the Dogger Bank Offshore Wind Farm Scheme, United Kingdom

Source: Universal Foundation

3.4 Crown Estate Demonstration Lease Round

Examples:

- Gunfleet Sands III
- Blyth Offshore Wind Demonstrator (formerly Test Site 1)
- Forthwind Offshore Wind Demonstration Project
- EOWDC (Aberdeen Bay)

Offshore wind farm development in the UK has taken place in a series of leasing rounds, promoted by The Crown Estate as the owner and manager of the majority of the seabed around the United Kingdom. Three main leasing rounds have occurred to date: December 2000 (Round 1), July 2003 (Round 2), and June 2008 (Round 3). An additional leasing round took place in Scotland in May 2008 (Scottish territorial waters) as well as a lease round of extensions to existing projects.

The entire first round of UK offshore wind farm development was described as a demonstration round, with a key aim of giving developers the opportunity to gain technological, economic, and environmental expertise. Subsequent rounds have been for much larger capacities.

In August 2010, The Crown Estate announced the award of offshore wind demonstration sites.[8] The awards followed an application process launched in May 2009 in response to the UK offshore wind industry's need to demonstrate new offshore wind turbines and other technologies in the marine environment. These demonstration projects were expected to address both technical and cost challenges to facilitate construction further from shore and in increasing water depths. Because of the demonstration aspect of the projects, they are each limited to less than 100 MW.

The demonstration round was awarded to four sites, two in England and two in Scotland:

- Gunfleet Sands extension (Gunfleet Sands III)—for testing up to two next generation offshore wind turbines.
- Blyth Offshore Wind Demonstration (formerly Test Site 1)—for a 100 MW grid connected site to test and demonstrate up to 20 next-generation offshore wind turbines and associated infrastructure.
- Forthwind Offshore Wind Demonstration Project (Methil)—to demonstrate an innovative two-bladed offshore wind turbine technology.
- European Offshore Wind Deployment Centre (EOWDC) Aberdeen Bay—to test and demonstrate next generation offshore wind turbines and other technology in Aberdeen Bay.

3.4.1 Gunfleet Sands III—Next Generation Offshore Wind Turbines

Ørsted (then DONG Energy) used an extension to its Gunfleet Sands offshore wind farm, approximately 8.5 km offshore, to test two next-generation offshore wind turbines.[9] This was the first time that the Siemens 6-MW turbine was tested offshore. A prototype of the turbine had been tested at an onshore test center at Hovsore, Denmark. The project formed an important part of the firm’s drive to further industrialize the offshore wind industry and so bring down the cost of energy.

3.4.2 Blyth Offshore Wind Demonstration (Formerly Test Site 1)—100 MW Grid Connected Test Site

EDF Energies Nouvelles is developing the proposed Blyth Offshore Demonstrator (BOD) wind farm off England’s northeast coast.[10] EDF acquired the rights to develop the project in October 2014, securing both the seabed rights from The Crown Estate and the associated land rights and meteorological data from the Offshore Renewable Energy Catapult (previously known as NaREC).[11]

The project will comprise an offshore wind farm located 6 km off the coast at Blyth. Permitting has been granted for up to 15 turbines. The initial installation includes five turbines with a maximum total generating capacity of 41.5 MW, incorporating new and innovative features. For the first time in an offshore wind project, the turbines have been installed on self-floating and submersible gravity-base foundations. In addition, the project has been the first to use 66-kV cable technology to connect the wind farm to the onshore substation.[12] The foundations are paired with MHI Vestas V164 turbines, each with a power rating of 8.3 MW.

As well as generating low-carbon electricity, the Blyth site gives EDF the ability to test and prove new and emerging technologies and to develop best-practice supply chain processes for the installation, operation, and maintenance of the wind farm. The project is expected to drive innovation for their French offshore sector projects, some of which require gravity-base foundations for geotechnical reasons.

Figure 4. Gravity-Based Foundations (GBFs) Prior to Load Out and Installation at the Blyth Offshore Demonstrator Site, United Kingdom

Source: P van Westendorp, Strukton Immersion Projects

3.4.3 Forthwind Offshore Wind Demonstration Project (Methil)—Two-Bladed Offshore Wind Turbine

A subsidiary of 2-B Energy is developing the Forthwind Demonstration Project. The primary purpose of the project is to validate the core technical concepts of the 2-B Energy technology, initially as a standalone turbine, and then as part of an array in an offshore environment. The project follows on from the installation, commissioning, and operation of the 2B6 prototype turbine at Eemshaven in the Netherlands.

The 2-B Energy turbine is strikingly different compared to more conventional designs, using a two-bladed rotor design in downwind orientation—allowing for stiffer blades with reduced clearances. A full-jacket construction with a wider footprint is also employed. Other innovations have been introduced to improve access and reduce construction and operational costs.[13]

Development consent was approved by the Scottish Government in December 2016, and the developer is now seeking funding to proceed.

Figure 5. Visualization of the 2-B Energy Wind Turbine Technology

Source: Forthwind Ltd

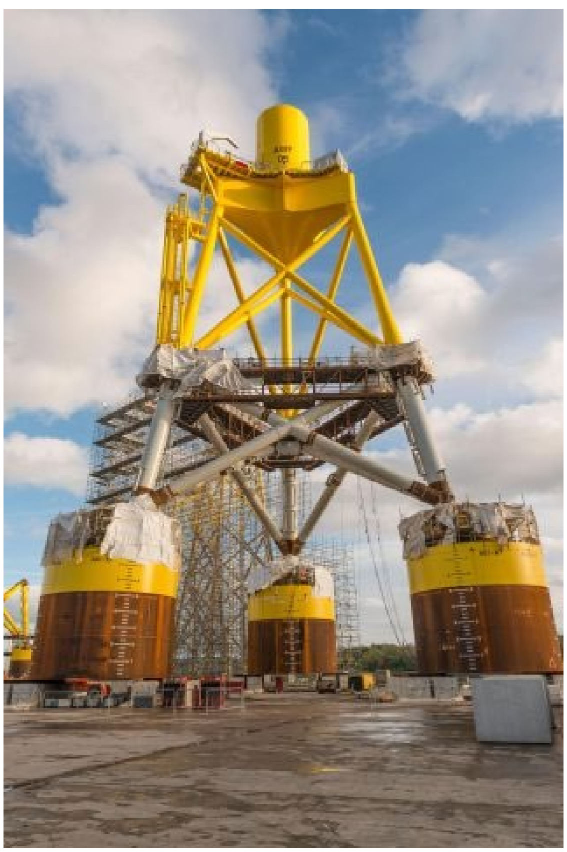
3.4.4 European Offshore Wind Deployment Centre (EOWDC) Aberdeen Bay—Next-Generation Technology

Located in Aberdeen Bay, the European Offshore Wind Deployment Centre (EOWDC) is Scotland's largest offshore wind test and demonstration facility. It is being developed by a subsidiary of Vattenfall. The scheme comprises 11 turbines with a capacity of 92.4 MW and will trial next-generation technology. MHI Vestas Offshore Wind V164-8.4 MW turbines are being paired with suction bucket foundations.[14] Construction of the facility, which also includes 66-kV cabling, began in October 2016 with first power generating in summer 2018. The facility is expected to operate commercially for 20 years. The EOWDC has been awarded up to EUR 40 m (c. USD 50 m) of funding from the European Union and is supported by Aberdeen Renewable Energy Group (AREG).

The suction jacket foundations are expected to be installed at the Aberdeen Bay site during January 2018, followed by the installation of the 66-kV inter-array cables and the export cable. The turbines are scheduled for installation in the second quarter of 2018.

Figure 6. EOWDC Suction Bucket Jacket Foundations

Source: Smulders



4 Conclusions

The offshore wind industry faces a challenge to reduce costs, and innovation has the potential to deliver and accelerate large-cost reductions.

Project developers are willing to undertake incremental technology development on a project-by-project basis where there is an economic driver or technical requirement to do so. However, it has been very rare for owners to integrate strategically directed testing and development for wind turbine foundation technology, or other testing, which imposes significant risks or costs onto commercial-scale projects.

Technology developers require demonstration sites to test equipment at various scales, ultimately to verify performance and achieve certification. There are many opportunities to innovate but commercializing the best ideas take time.

Demonstration projects and testbeds are needed to reduce risk and increase confidence in new technology, especially for advanced turbines and innovative foundations. Ultimately, equipment must be tested at full-scale and under commercial operating conditions. In many regions, demonstration projects have been used to gain experience in offshore wind technology at a manageable scale before large deployment. This also helps prepare local supply chains.

Where offshore wind is more established, some of the most successful test sites have been extensions to existing wind farms, allowing testing of small numbers of turbines or foundations while using existing grid infrastructure and maintaining efficiencies of scale.Authorities have encouraged demonstration testbeds in the range 20-100 MW, through specific lease rounds or competitive tenders. Such tenders typically provide enhanced subsidy if certain criteria are met and milestones delivered. Ultimately, demonstration in commercial projects must be economic for the project proponent, and it can be assumed that such projects must meet the same financial hurdles as full-scale commercial projects.

The global offshore wind market has been asking for opportunities to develop offshore test projects. Offshore test facilities can potentially reduce production costs of electricity from offshore wind farms, and thereby keep offshore wind energy competitive.

With test and demonstration projects typically lead by developers as commercial ventures, a key challenge for the leasing authority and regulators is ensuring that maximum value is gained through the provision of research and development funding, and that the knowledge and experience gained from testing and development is shared appropriately.

Appendix A. Floating Offshore Wind Projects

The focus of the report is on fixed-foundation testbed facilities as these are most appropriate analogues for potential projects on the United States Atlantic seaboard. To provide an overall perspective, this appendix contains information on floating offshore wind testbed facilities. While not directly relevant, some of the projects contain valuable knowledge for structuring such facilities.

Table A-1. Offshore Wind Demonstration Projects—Floating Projects

Source: RCG Global Renewable Infrastructure Projects database

Project	Purpose	Capacity (MW)	Country	Status
EUROPE				
Blekinge Demo	Semi-submersible floating foundation	24	Sweden	Development
Dounreay (DFOWDC)	Tension leg platform	30	Scotland	Abandoned
Dounreay Tri Demonstration Project	Semi-submersible floating foundation	16	Scotland	Consented
EolMed (Pilot Farm)	Semi-submersible floating foundation	24	France	Development
Floatgen (SEM-REV)	Semi-submersible floating foundation	2	France	Construction
Gicon SOF	Tension leg platform	2	Germany	Consented
Groix & Belle-Ile Demo	Semi-submersible floating foundation	24	France	Development
Hywind	Spar buoy floating foundation	2	Norway	Operational
Hywind Scotland Pilot Park (Hywind 2) Demonstrator	Spar buoy floating foundation	30	Scotland	Construction
Kincardine Offshore Wind Farm (KOWL)	Semi-submersible floating foundation	49	Scotland	Consented
Les Eoliennes Flottantes du Golfe du Lion (LEFGL)	Semi-submersible floating foundation	24	France	Development
Provence Grand Large Demo	Tension leg platform	24	France	Development
WindFloat 1 Prototype (WF1)	Semi-submersible floating foundation	2	Portugal	Decommissioned
WindFloat Atlantic (WFA)	Semi-submersible floating foundation	25	Portugal	Consented
ASIA				
Fukushima Forward Demo 1	Semi-submersible floating foundation	2	Japan	Operational
Fukushima Forward Demo 2	Semi-submersible floating foundation	7	Japan	Operational
Fukushima Forward Demo 3	Advanced spar floating foundation	7	Japan	Operational
WindFloat Japan (WFJ)	Semi-submersible floating foundation	6	Japan	Scoping
NORTH AMERICA				
Hywind Maine	Spar buoy floating foundation	12	USA	Abandoned
Maine Aqua Ventus 1	Semi-submersible floating foundation	12	USA	Development
Windfloat Pacific Demo (Coos Bay)	Semi-submersible floating foundation	24	USA	Abandoned

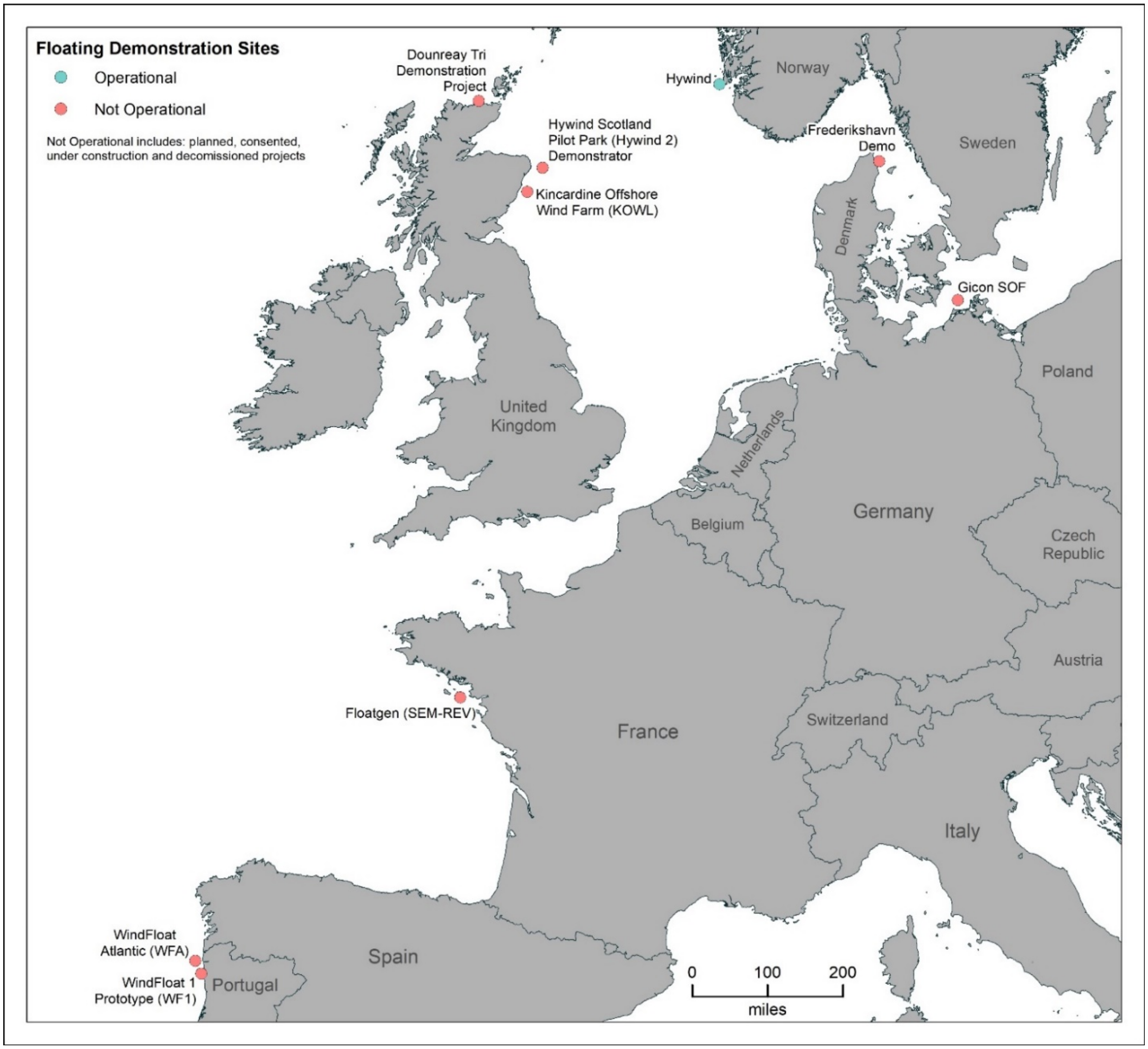
Table A-1. (continued)

Source: RCG Global Renewable Infrastructure Projects database

Test Site	Ownership	Status	Delivery Route	Year Operational	Technology tested / to be tested	WTG Capacity	Comments
Blue H	Blue H (100%)	Decommissioned	Demonstration	2007	Single semi-submersible floating structure with 80 kW wind turbine	0.08 MW	Blue H installed the system off the coast of Puglia, Italy, with a 80 kW 2-bladed wind turbine.
Hywind	Statoil ASA (100%)	Operational	Demonstration	2009	Spar buoy with Single SWT-2.3-82 wind turbine (2.3 MW)	2.3 MW	Single spar buoy installed
WindFloat 1 Prototype (WF1)	WindPlus (100%)	Decommissioned	Demonstration	2011	Single semi-submersible floating structure with Vestas V80 (2 MW)	2 MW	Decommissioned in 2016 following 5-year deployment
Hywind Scotland Pilot Park (Hywind 2) Demonstrator	Statoil ASA (75%) Masdar (25%)	Operational	Demonstration	2017	5 x spar buoys with Siemens SWT-6.0-154 wind turbines (6 MW)	6 MW	Delivered under Scottish system providing
Floatgen (SEM-REV)	Ideol (100%)	Under Construction	Demonstration	Under Construction	Single semi-submersible floating structure with Vestas V80 (2 MW)	2 MW	Due to be commissioned in early 2018.
Gicon SOF	GICON GmbH (100%)	Consented	Demonstration	Consented	2 x semi-submersible floating structure		Electrical transmission intended to be via Baltic I substation
Dounreay Tri Demonstration Project	Hexicon AB (100%)	Consented	Demonstration	Consented	Single semi-submersible floating structure supporting 2 x 5 MW wind turbines		Novel 2-WTG floating structure.
WindFloat Atlantic (WFA)	EDP Renováveis SA (19%) Engie (10%) Diamond Generating Europe Limited (20%) Chiyoda Generating Europe (20%) Repsol S.A. (19%) Principle Power Inc. (1%) Marubeni Corporation (10%)	Consented	Demonstration	Consented	Submersible floating structures with up to 4 wind turbines, with total capacity up to 25 MW		Previously tested WindFloat technology with a 2 MW wind turbine.

Figure A-1. Location Map of European Demonstration Sites—Floating Foundation

Source: RCG



Some full-scale floating offshore wind demonstration sites have either recently entered operation or are consented. Other projects are known to be currently in development, although these are not presented in Table A-1.

A.1 Turbine Testing

Wind turbines experience significantly different forces when operating on a floating foundation, particularly during start-up and shut-down phases. This requires validation of structural engineering and refinement of control systems.

Both MHI Vestas and SiemensGamesa have supplied and operated wind turbines for floating demonstration structures, with SiemensGamesa recently supplying 6-MW wind turbines to the Hywind Scotland project and MHI Vestas supplying the WindFloat Atlantic scheme.

A.2 Foundation Testing

Test sites have been used to test jackets, tripods, and gravity bases prior to large-scale deployment. In recent years, many demonstration sites entering development have been driven by the potential for the floating wind market, and the current technical immaturity of the technology. This is to be expected, particularly given the number of active foundation technology developers and corresponding foundation concepts, all of which should be tested and demonstrated at full-scale to increase their respective technology readiness level (TRL) prior to any commercial-scale deployment. However, these demonstration sites must still operate commercially, and as such, require the financial support to do so.

Endnotes

1 The focus of this study is on fixed-foundations. To provide an overall perspective, information on floating offshore wind projects is contained in a separate appendix.

2 European Energy Programme for Recovery: http://ec.europa.eu/energy/eepr/projects/

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10 Blyth Offshore Wind Farm Project Hits New Milestone (EDF Energy Renewables; July 11, 2017) http://www.edf-er.com/News/LatestNews/tabid/613/entryid/98/blyth-offshore-wind-farm-project-hits-new-milestone.aspx

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12 Offshore Wind Foundations A European Overview (RCG; September 18, 2017) https://thinkrcg.com/wp-content/uploads/2017/09/RCG-Insight-2017-09-18-Offshore-wind-foundations.pdf

13 Vital design considerations for an optimal wind plant design (2-B Energy; accessed January 5, 2018). http://2benergy.com/windturbine/design-considerations/

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