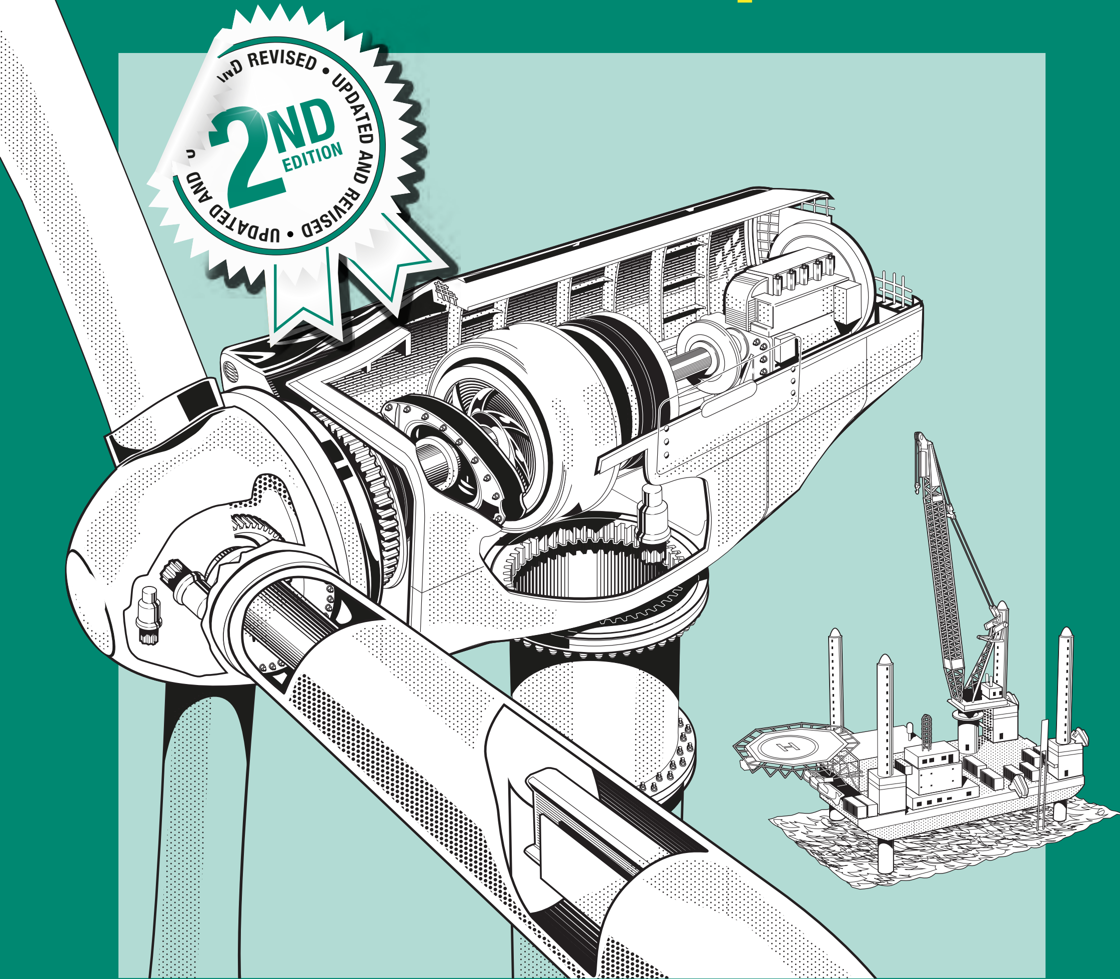
OFFSHORE WIND ENERGY

Powering the UK since 2000

RUK16-032-6

Owners' Workshop Manual



An insight into the design, engineering, construction and history of a 21st century power source

renewableUK
The voice of wind & marine energy

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Introduction

In the waters around the British Isles, an energy revolution is taking place. Thousands of wind turbines, some the height of landmark skyscrapers such as London's Gherkin, are being installed to meet the UK's energy needs.

Why is this happening in the UK? Quite simply because Britain has the best offshore wind energy resource in the world, leading some to call it "the Saudi Arabia of Offshore Wind".

Over the years, energy experts and scientists have studied this resource in detail. According to research, the available wind resource around Britain's coasts is so great that utilising around 30% of it would generate the annual energy equivalent to that of 1 billion barrels of oil and make the UK a net electricity exporter. Even a more modest 13% utilisation would be enough to supply half of the UK's electricity demand.

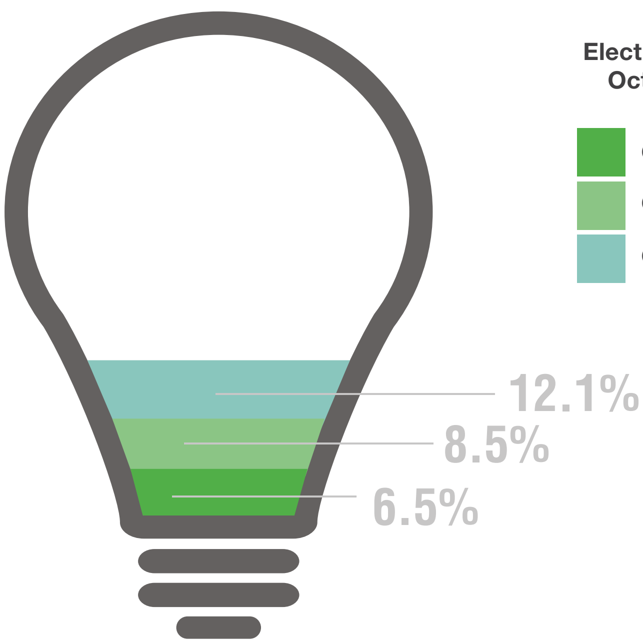
Offshore wind farms take up 0.1% of the UK's sea area and generate close to 7% of electricity.

In addition to this research, we now have real-life UK operational data, since the first installed turbine started supplying power to the grid 15 years ago. And the results are impressive: it turns out that every 1,000 Megawatts (or 1 Gigawatt) of installed offshore power capacity contributes roughly 1% of the UK's net electricity supply. Given the power capacity of modern offshore 'super turbines', this contribution could be achieved by installing just 125 machines, such as the new MHI Vestas Offshore Wind's (MVOW) V164.

Such tremendous amounts of energy can be extracted from a relatively small surface of the ocean. In fact, all the wind farms installed to date in the UK's part of the North and Irish Seas, which currently supply close to 7% of the nation's electricity, are taking up just over 0.1% of the area. This represents a new way to generate power, with minimal impact on land resources.

And the United Kingdom needs power. The nation is the world's fifth industrial power, and the third most populous nation in the EU. And while demand for electricity has grown since the 1980s, 20% of the UK's existing generation capacity is due to be retired over the next decade, as its aging coal and nuclear plants are decommissioned. North Sea oil and gas fields are in decline, leaving the UK dependent on imports of foreign gas.

Fortunately, the UK has begun to grasp the offshore wind opportunity. From a slow start, it has become the undisputed world leader in the sector. In Europe, the chief market for offshore wind, UK has 46% of the total capacity installed, compared to 30% for Germany and 11.5% for Denmark.



Electricity generation in the UK
October to December 2015

Offshore wind 6.5%
Onshore wind 8.5%
Other renewables 12.1%

Since 2010 the UK has been putting a wind turbine in the water on average every 40 hours.

Since the first wind turbine was installed near Blyth off the UK's North East coast in 2001, close to 2,000 turbines have already been installed or are in construction in UK waters.

But challenges lie ahead. The offshore wind industry is moving fast into the mainstream and supplying an ever-larger proportion of power demand. As it does so, it faces competition, chiefly on price, from other energy sources, including nuclear, gas and solar, and intense pressure from government to bring costs down further.

In order to achieve cost reduction while being tasked with providing ever more energy, offshore wind developers are building bigger and bigger projects, using new mega-machines and moving further offshore into deeper waters. Building the next generation of wind farms constitutes one of the biggest engineering challenges of our time.

If it can rise to the challenge, the offshore wind industry's achievement will be comparable to the building of the country's railways in the 19th century. Across Europe, hundreds of thousands of people will be working—directly or indirectly—in the offshore wind industry. The UK has been putting a wind turbine in the water on average every 40 hours.

This Haynes Guide, prepared by RenewableUK with the support of MVOW, will tell you what you need to know to understand this exciting new industry.

Section 1. What is offshore wind power?

The rise of wind power

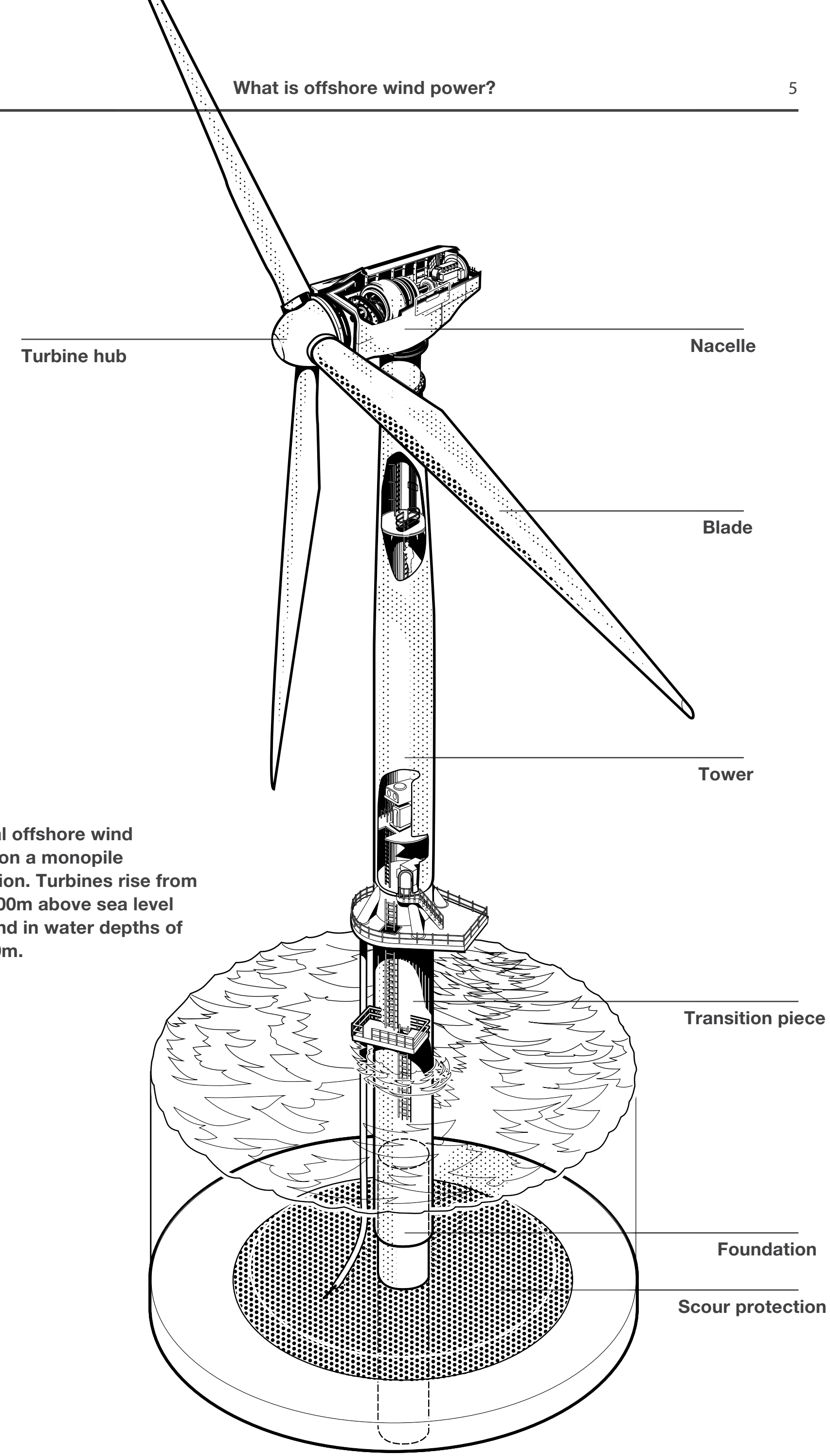
Wind power has been one of the fastest growing power sources in the world over the last two decades. Cumulative installations have grown from a tiny 7.6 gigawatts (GW) in 1997 to 433GW in 2015, representing an average growth rate of over 25% per year. This means that from a few thousand wind turbines globally 20 years ago, there are now close to 300,000 in operation.

The wind sector has grown from a few thousand wind turbines 20 years ago to 300,000 today.

The advantages of wind power are that it is relatively quick to install, it is scalable—a wind farm can be made up of a couple of turbines or up to hundreds of turbines—and it is clean and carbon free. This latter factor has made wind attractive to governments trying to meet carbon targets and stop climate change, large corporations with their own sustainability targets, and also the general public.

In addition, the economics of wind farms are predictable. After construction, wind farms do not depend on the supply of fuels whose prices are volatile, and average wind speeds at wind farm sites can be predicted on an annual basis with a high degree of reliability.

Until recently, wind power was relatively expensive compared to more traditional forms of power generation. It largely relied on government support schemes of different types to be competitive, although it is also worth pointing out that fossil fuels have traditionally enjoyed less obvious forms of support, such as tax breaks.



A typical offshore wind turbine on a monopile foundation. Turbines rise from 150m-200m above sea level and stand in water depths of up to 50m.

However, wind power costs have fallen steadily, particularly in recent years, as wind turbines become cheaper and more efficient. These cost and efficiency improvements are driven by technological innovations such as bigger rotor blades and more sophisticated electronic control systems. Finance for wind farms is also becoming cheaper and more available. This means that onshore wind is now often cheaper than any other available power generation source in large areas across the world, from Europe to the US, Brazil and China.

Why go offshore?

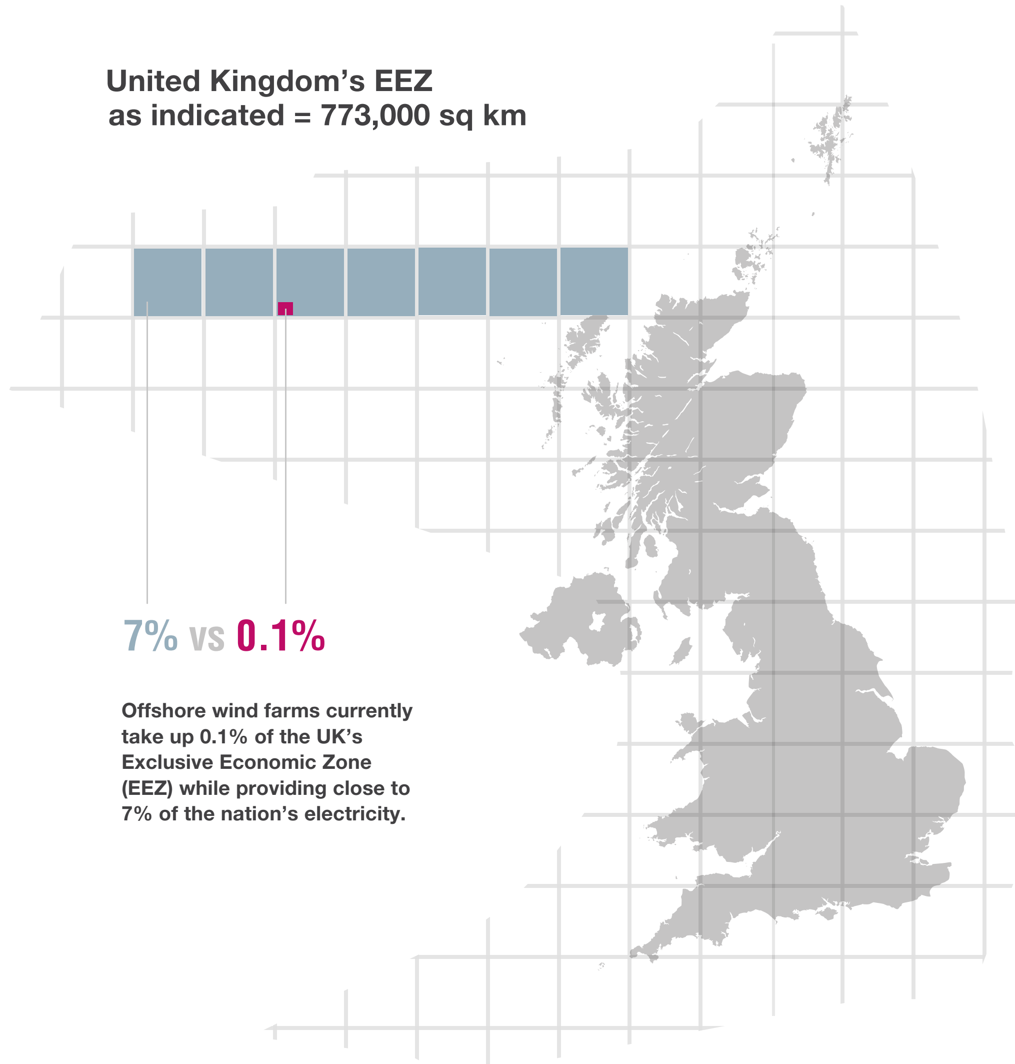
Onshore wind is relatively quick and easy to install, but why take wind offshore? The answer is both economic and political. In any case, there are a number of factors to consider.

Winds offshore are both stronger and more consistent than onshore, so operators can reap significantly higher amounts of energy than they would from most onshore sites. On the other hand, as we shall see, the challenges of constructing offshore are significant, and installation costs subsequently much higher.

In addition, the space available to build wind farms offshore is enormous and not subject to the same planning or infrastructure constraints as potential onshore sites. For developers, officials and the public, this is an important factor to consider.

To build offshore wind on any scale, countries need both good wind resources and a compelling reason to go offshore. For instance, the USA has good offshore wind, especially on its East Coast, but it has traditionally had abundant development opportunities for onshore wind.

The UK, as an island nation, has a huge amount of space for developing offshore wind farms, and we have seized the opportunity to take a global lead in its development.



Offshore wind farms currently take up 0.1% of the UK’s Exclusive Economic Zone (EEZ) while providing close to 7% of the nation’s electricity.

The UK's potential is estimated at 120GW using only waters with depths under 50m. This is sufficient to supply all of the UK's electricity.

The resource prize

The seas of Northern Europe offer the best offshore wind resources in the world, such that a relatively small area in the North Sea could create enough energy to supply all of Europe's electricity. Conducive to development is also the fact that most of the North Sea is shallow. Large parts of it were actually land, until they were submerged at the end of the last Ice Age around 8,500 years ago.

The UK, which has become the world leader in the sector, is fortunate to have the best offshore wind resources of any country in the world, with a total potential estimated at 120GW using only waters with depths of under 50 metres. This capacity is sufficient to supply all of the UK's electricity—and still leave some for export!

With its long coastlines, the UK has the fifth largest Exclusive Economic Zone (EEZ) in the world, giving companies huge potential to develop wind farms in its waters.

It is also close to a number of other countries—Germany, Denmark, France—with their own significant wind resources and wind industries. This means that the UK can benefit from a network of industrial capacity and skills, while Europe as a whole can share the energy output from offshore wind farms. The growing interconnectivity between Europe's electricity grids, facilitated by offshore wind farms, could soon lead to the buildout of a European "Supergrid". This initiative could pool renewable energy resources across Europe to help balance supply and demand—another important role for offshore wind.

A turbine on a monopile foundation at North Hoyle—the first full-scale offshore power plant in the UK. The crew transfer vessel is seen docking at the transition piece access ladder.

The engineering challenge

However, harvesting this resource constitutes a colossal engineering challenge, across a number of sectors. Installing turbines in deep, rough waters entails the manufacture of stable towers for them to sit on. Then there is the installation of these towers, which can be over 100m tall, in constantly changing, hostile weather.

Once installed, the turbines must work reliably over long periods of time, withstanding the strong winds, storms and corrosion from salt water. In addition, the wind farms need to be connected to electricity grids onshore, which are often great distances away. This requires the building of offshore substations and the laying of long power cables on the seabed.

These challenges have inverted the traditional economics of developing a wind farm. In onshore projects, the wind turbine itself makes up around 65–70% of the cost of the project, while in a typical offshore project this may be only 40–55% because of the steep costs of building foundations, installing the turbines and connecting the projects to the shore.

Because the costs of installing foundations and other infrastructure are relatively inelastic, and projects do not face the same height restrictions as onshore, it makes sense to try to increase the size of individual wind turbines. This has led to a steady increase in size of the machines to reach today's giant 5 megawatt (MW), 8MW and even 10MW designs. In comparison, an average onshore turbine has a capacity of 1.6MW. To illustrate, a 8MW turbine provides sufficient electricity on an annual basis for up to 5,700 UK homes—just 35 such turbines could power every home in the city the size of Manchester.

Section 2. The history of offshore wind

The first projects

A 1GW offshore wind farm provides electricity for over 700,000 homes per annum.

The first offshore wind farm was built in 1990/1, 2.5km off the coast of Denmark, at Vindeby. It consisted of specially adapted onshore 450 kilowatt (kW) turbines built by Bonus and designed by wind turbine pioneer Henrik Stiesdal.

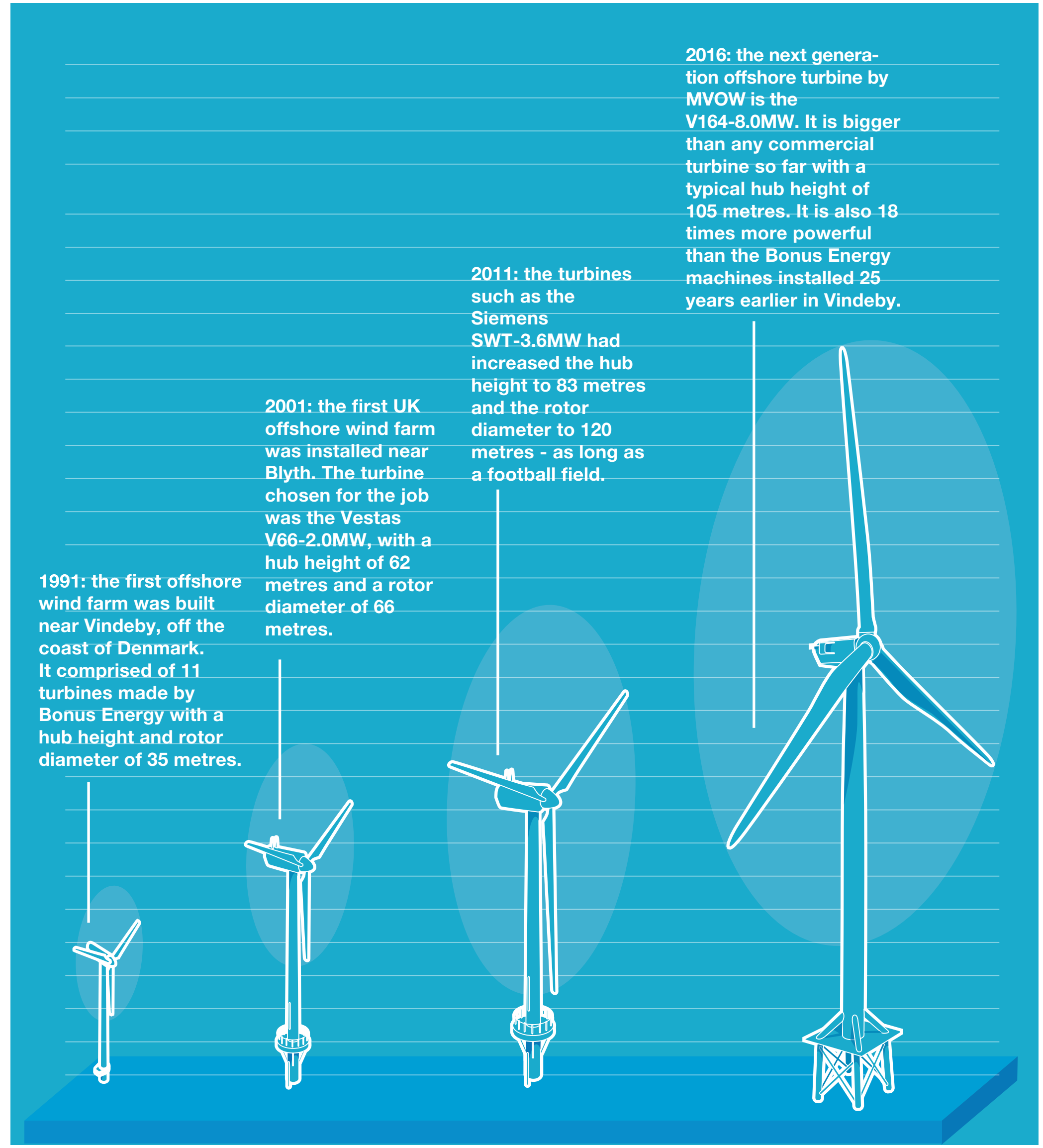
In the following years growth was slow, with only a small number of projects being developed close to shore in Denmark and the Netherlands. It was not until 2000 that the first large-scale project was built at Middelgrunden in Denmark, which had twenty 2MW Bonus turbines. The project was developed by Danish utility DONG Energy.

The UK gets involved

In the same year, the first offshore wind farm in the UK was built, off the coast of north-east England, close to the city of Newcastle. Blyth Offshore consisted of two 2MW Vestas turbines and was developed by a consortium including utility E.ON and oil giant Shell, within the framework of the UK's Non-Fossil Fuel Obligation (NFFO) support scheme.

A couple of years earlier, in 1998, the British Wind Energy Association (now RenewableUK) had held discussions with government and The Crown Estate, which owns the seabed around the UK, to create a set of guidelines allowing offshore wind development to take place. The published guidelines permitted companies to develop wind farms of an area of up to 10km² and 30 turbines. This provided the opportunity for companies to gain valuable development experience.

Offshore wind turbines have increased in size over the years, in line with advancements in turbine technology and construction



In what became known as the UK's Round 1 licensing round exercise, 17 projects were approved and given permission to proceed in April 2001. The first Round 1 project, North Hoyle, was completed in 2003, followed by a further 10 projects, with a total of 1.1GW. But this was just the start. Round 2 took place in 2003, with 15 projects awarded a total capacity of 7.2GW.

Round 2 led to a rapid growth in the UK's offshore capacity and to the UK quickly becoming the world leader. Two Round 2 projects—Gunfleet Sands and Thanet—were completed in 2010, with several others following over the next couple of years, including the completion of the giant London Array project in early 2013. As we shall see, however, these would soon be dwarfed by a much more ambitious licensing round.

In terms of turbines installed, this means that the UK went from two offshore turbines in 2002 to around 50 in 2004 and close to 100 by the end of 2005. A decade down the road, in 2016 the country has around 2,000 offshore turbines either in construction or in operation. In fact, since 2010, an offshore wind turbine went up in UK waters on average every 40 hours.

EU and global growth

From 2000, offshore wind steadily picked up momentum. In 2001, the 50.5MW installed offshore in Europe represented just 1% of the total wind capacity. By 2014, however, offshore wind represented 12.4% of a much larger total of 11.8GW. By the end of 2014, 8.8GW had been installed offshore globally.

London Array, the world's biggest offshore wind farm, as seen from space. A Round 2 project in the Thames Estuary, it consists of 177 turbines at 480 tonnes each over an area of 100km^2. Site water depth is up to 25m and the distance between turbines is 650–1,200m. (Image courtesy of NASA)

At the opening ceremony in 2013 Prime Minister David Cameron said: "London Array has been built by some of the bravest seamen, the most talented engineers and hardest workers."

The Round 3 bonanza

In June 2008, The Crown Estate launched Round 3. The prize: nine offshore wind development zones with a potential wind power capacity of 33GW. To illustrate the magnitude: if developed, 33GW could provide one third of the UK's electricity demand.

Round 3 also called for bids for a number of sites in Scottish territorial waters. The Round's smallest zone, Rampion, had a potential capacity of 700MW, as large as the biggest project thus far in development, the London Array. The largest, Dogger Bank in the North Sea, had a potential capacity of 9.2GW, exceeding the total capacity of the UK's nuclear fleet.

In Round 3, 33GW of sites was announced. To illustrate the magnitude, 33GW of offshore wind power could provide one third of the UK's electricity demand on an annual basis.

The bidding round created a fervour of interest among project developers and manufacturers, attracting 40 applications, with multiple bids for each zone on offer. The successful bidders included a number of major power companies such as Iberdrola, SSE, RWE, E.ON, and Centrica, and Norway's Statoil and Statkraft, as well as developers such as Mainstream Renewable Power, which partnered with Siemens.

The Round 3 announcements created interest from around the world in the UK's offshore scene. A number of big industrial companies, from Europe, Asia and the US, announced decisions to start manufacturing the huge new turbines that would be needed in this round. From 2008 to 2010 these companies, including Vestas, Siemens, GE, Gamesa and Clipper, began to identify factory sites and take out leases. Others, such as Korea's Samsung, Hyundai and Doosan, and Japan's Mitsubishi Heavy Industries (MHI) also prepared to enter the game.

The growing development ambitions of the UK's offshore wind sector

Round 1, 2001, 1.5GW of sites available.

Round 2, 2003, 7.2GW.

Round 3, 2008, 33GW

The onset of harder times for European power companies and turbine manufacturers, coinciding with the world-wide economic crisis and coupled with the the new UK Government's decision to close the Renewables Obligation scheme and replace it with a new Contracts for Difference (CfD) framework, marked the the onset of a more mature and sober outlook.

Project timeframes for current and planned offshore wind farms began to lengthen, particularly because of the uncertainty around the new regulatory scheme and the future size of the UK's ambition. The landmark Clipper Britannia project to build a 10MW turbine was cancelled in August 2011, while other developers and supply chain companies put plans on hold.

However, this period of uncertainty was also a period of consolidation and renewal. The construction of already licensed projects and extensions in UK waters continued steadily, while in the background the work of planning the first Round 3 projects was taking place. On the manufacturing side, Germany's Siemens obtained planning permission for its Green Port Hull facility in May 2012, and started work on the site in March 2014, which will create 1,000 jobs.

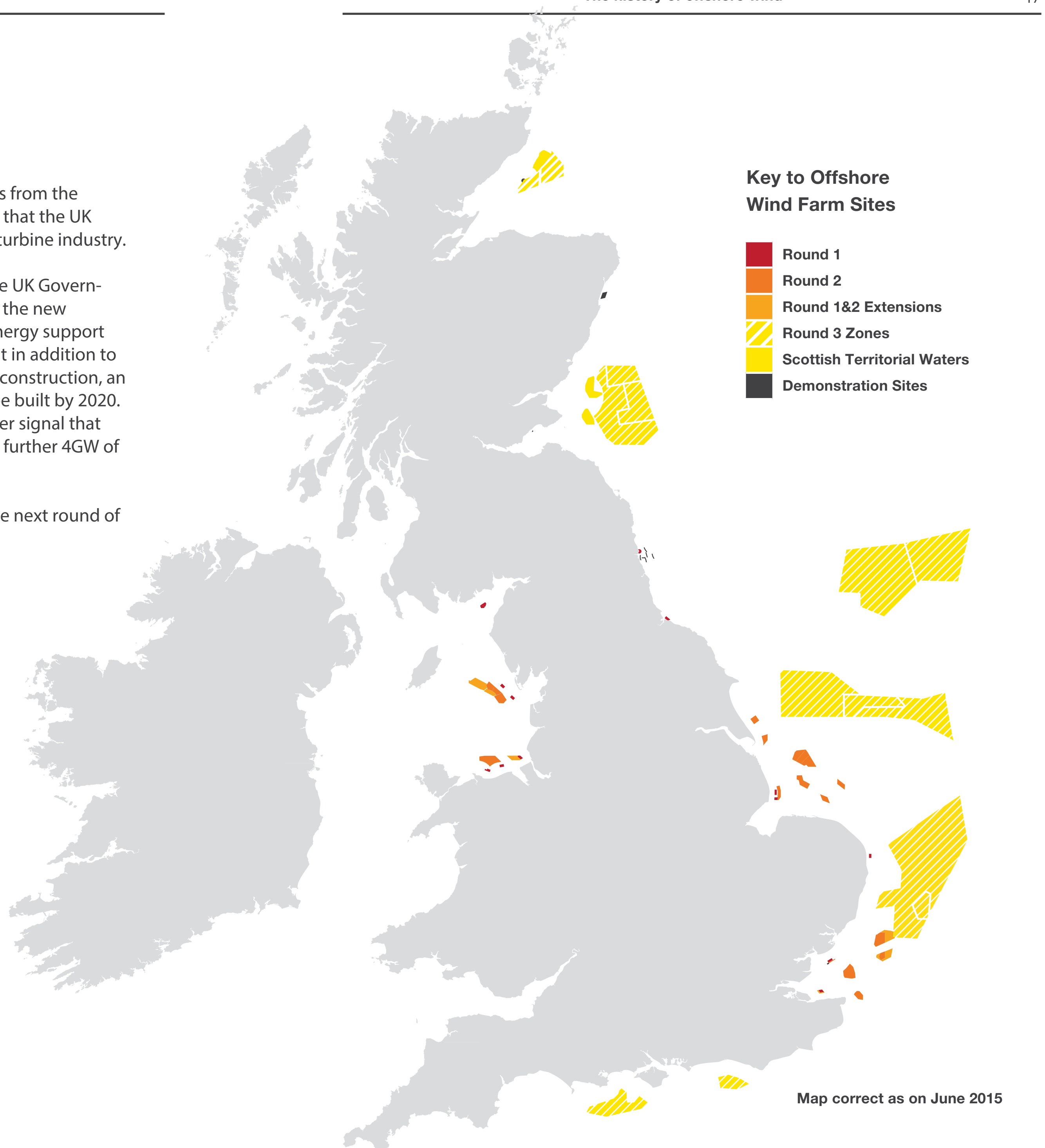
A few months later, Vestas announced a joint venture with Mitsubishi Heavy Industries, under the MVOW brand. The partnership announced that it would build the blades for its giant 8MW turbine on the Isle of Wight. Since the announcement, MVOW has also taken over a preassembly site in Belfast Harbour. This means that

The bidding for Round 3 Zones created a fervour of interest among project developers and manufacturers, attracting 40 applications, with multiple bids for each zone on offer.

taken together, these announcements from the industry's main manufacturers meant that the UK would once again have its own wind turbine industry.

And in 2014 through to early 2015, the UK Government awarded seven contracts under the new Contracts for Difference renewable energy support framework. Effectively, this meant that in addition to the 5GW of projects in operation and construction, an additional 4.5GW of projects should be built by 2020. In 2016, the Government gave a further signal that there could be funding available for a further 4GW of offshore wind capacity by 2025.

All in all, the stage had been set for the next round of growth in offshore wind.



Section 3. How offshore wind farms are developed

The process of planning, building and operating wind farms is carried out by companies known as developers. These include:

- ***Utilities companies***, which often produce and distribute power from a number of sources, often in a number of different countries, such as Iberdrola/ Scottish Power or DONG Energy.
- ***Independent developers***, some of which go on to operate the wind farms as Independent Power Producers, while others aim to sell off part or all of their wind farms once they have actually been built.
- ***Others*** such as oil and gas companies that want to diversity into wind power, such as Statoil and Shell.

The role of The Crown Estate

In the UK, development starts with an application to The Crown Estate. The Crown Estate is the body that manages the land and marine assets formally owned by the sovereign, but controlled and administered by government. These assets include the seabed out to 12 nautical miles and most of the coastline around the UK.

It also controls the rights to generate electricity from wind, waves and the tides on the UK continental shelf, under the Energy Act of 2004.

The Crown Estate has taken a proactive role in the development of offshore wind power, in line with its mandate of maintaining and enhancing the value of its portfolio and the economic return from it. This has included organising and promoting successive rounds for leasing of development areas. But it is also active in a number of other spheres in order to ensure that the potential of the areas is realised. These include carrying out large-scale studies; supporting the development of a UK offshore wind supply chain; and enabling the sharing of data and best practices.

In the UK, the development process starts with The Crown Estate.

In the UK the first stage of development of an offshore wind farm is an exclusivity agreement for a particular development zone signed between the developer and The Crown Estate. This is followed by an Agreement for Lease. This agreement gives the developer exclusivity over an area of seabed—in other words, seabed rights. This entails an enforceable option to require The Crown Estate to grant a lease, subject to the developer obtaining the necessary consents. It also grants to the developer temporary rights to carry out activities in the area, such as surveying or wind measurement work, and the right to add an export cable route at the appropriate time.

The life cycle of an offshore wind farm: from site scoping to decommissioning

The consent process

Once they have an AfL from The Crown Estate, developers need to apply for planning permission. In England and Wales, applications for projects of over 100MW of generation capacity need to apply to the Planning Inspectorate-smaller projects need to be submitted to the Marine Management Organisation or Natural Resources Wales respectively. In Scotland, applications for all marine projects need to be submitted to Marine Scotland.

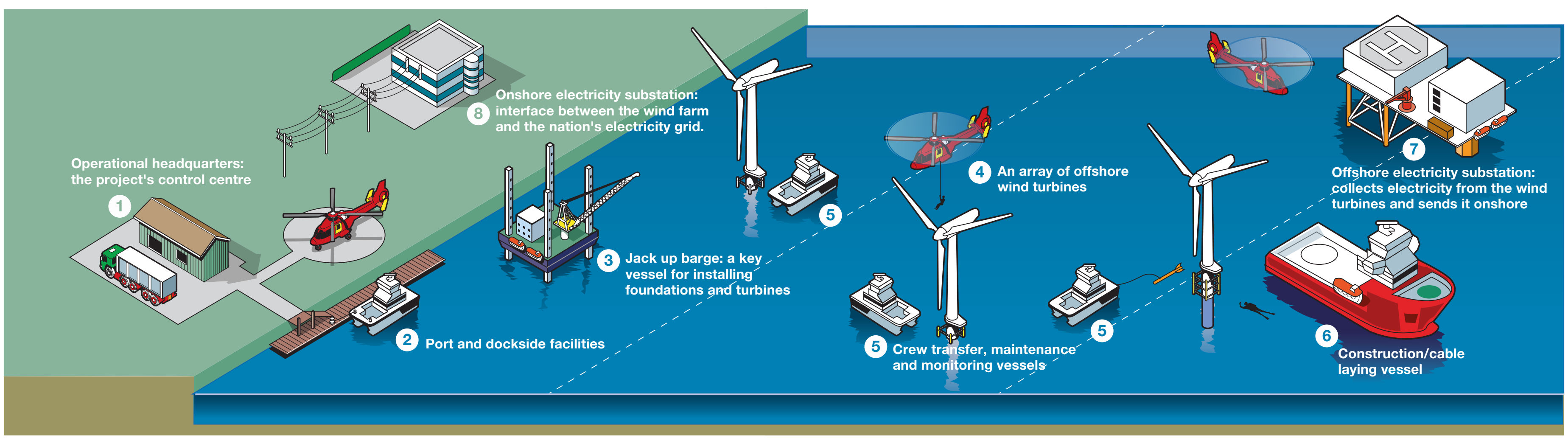
The application needs to include details of a developer's project design—for example, the exact location of the wind farms within the zone, the number and size of wind turbines to be used, the proposed location of any onshore substations that will have to be built, an Environmental Impact Assessment, and evidence that detailed consultation on the project has taken place with stakeholders such as local communities or fishermen.

The planning application is a voluminous document running to 10,000 pages or more, and is put together by expert teams looking at every aspect of building and operating the wind farms over the lifetime of the project. Developers need to show that environmental and social concerns around the impact of the individual projects have been identified during the consultation and addressed in preparation for the consent application.

Following the submission of this evidence, the relevant planning authority then carries out its own consultation on the application. It does so by weighing up the benefits and potential adverse effects of a project, before deciding whether it can be built. If approved, the planning authority then issues a planning consent, which in England and Wales is called a Development Consent Order.

Historically, the length of this process has varied. It most cases it takes around five years, but can last longer if there are particularly complex environmental or social issues to consider.

The main elements of an offshore wind farm

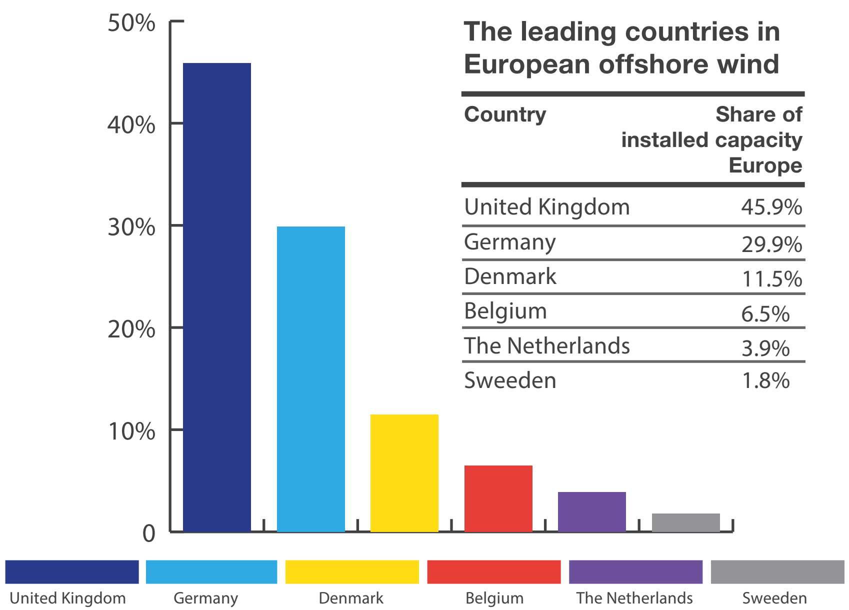


Site selection and design

Before making its consent application, a developer will create a detailed design for the wind farm it intends to build. Often the developer will plan to build a number of separate projects (wind farms) over a number of years within the zone that it has rights to.

In order for the site plan to be created, a number of factors need to be taken into consideration. The first is wind speed. The developer will put up anemometry masts (known as “met masts”) to measure wind speed at various points in the site and/or use floating LIDAR technology, which uses lasers to measure wind speed. The data generated are used to decide the optimum locations for the wind farm projects and turbines.

The second important factor is water depth. Water depths can vary significantly within a zone, and this will impact the kind of foundations—and therefore the cost—of projects.



The leading countries in European offshore wind

Country	Share of installed capacity Europe
United Kingdom	45.9%
Germany	29.9%
Denmark	11.5%
Belgium	6.5%
The Netherlands	3.9%
Sweeden	1.8%

The third factor is seabed conditions. Developers will carry out detailed surveys on the seabed, as factors such as the quality of the soil or the presence of large amounts of rocks and other obstacles can affect the complexity—and therefore the cost—of installing foundations. In some cases, such as the giant Dogger Bank Round 3 zone, planning may even need to take into account the need to protect archeological remains on the seabed.

The fourth factor is environmental concerns, such as the possible impact of a wind farm project on wildlife. An example is the giant London Array wind farm in the Thames Estuary, which saw its design modified to limit the impact on red-throated diver birds.

Once a site plan has been approved and the consent order has been issued, the work of constructing the wind farm can begin.

The main offshore wind developers/owners

Developer	Cumulative installations Europe
DONG Energy	15.6%
EON	9.6%
RWE Innogy	9%
Vattenfall	8.8%
Stadtwerke Munich	3.8%
Oceon Breeze Energy	3.6%
SSE	3.2%
Green Investment Bank	2.8%
Blackstone	2.1%

Section 4. How offshore wind farms are constructed

Building the foundations

The first challenge in constructing a wind farm is deciding what kind of foundations the project's turbines will be supported on. There are three main types of foundations which have been deployed in commercial projects.

The first construction challenge is deciding on the type of foundation that will support the wind turbine.

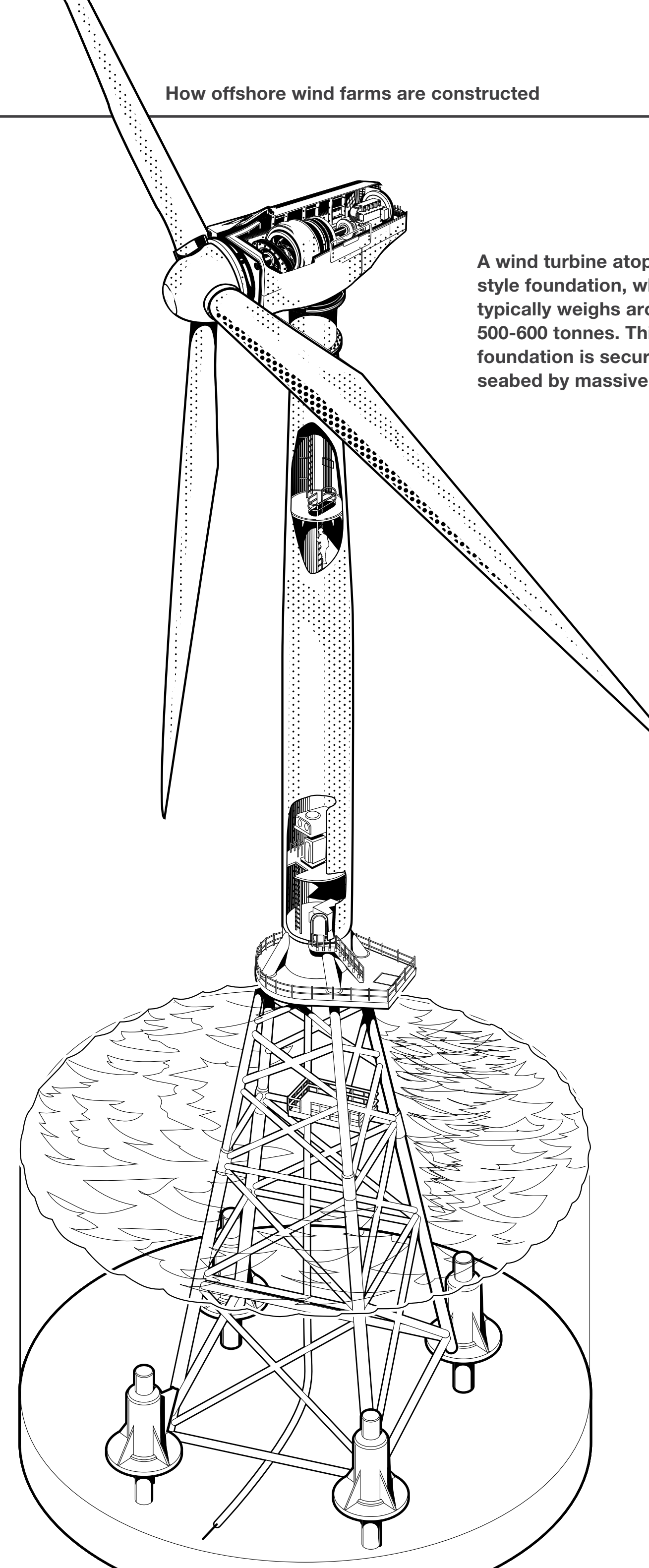
The majority of wind farms constructed up to now have been built using steel monopiles—large tubes, typically weighing up to around 600 tonnes, that are driven into the seabed. Depending on the length, the diameter of the monopile can be up to 6 metres and the tube walls can be as much as 150mm thick.

A transition piece (TP) is then put on top of the monopile, onto which the turbine's tower and other equipment, such access ladders, can be bolted. The TP is fixed in place with high-strength cement called grout, a process that allows the installer to make sure the piece is exactly vertical and at the right height above the sea.

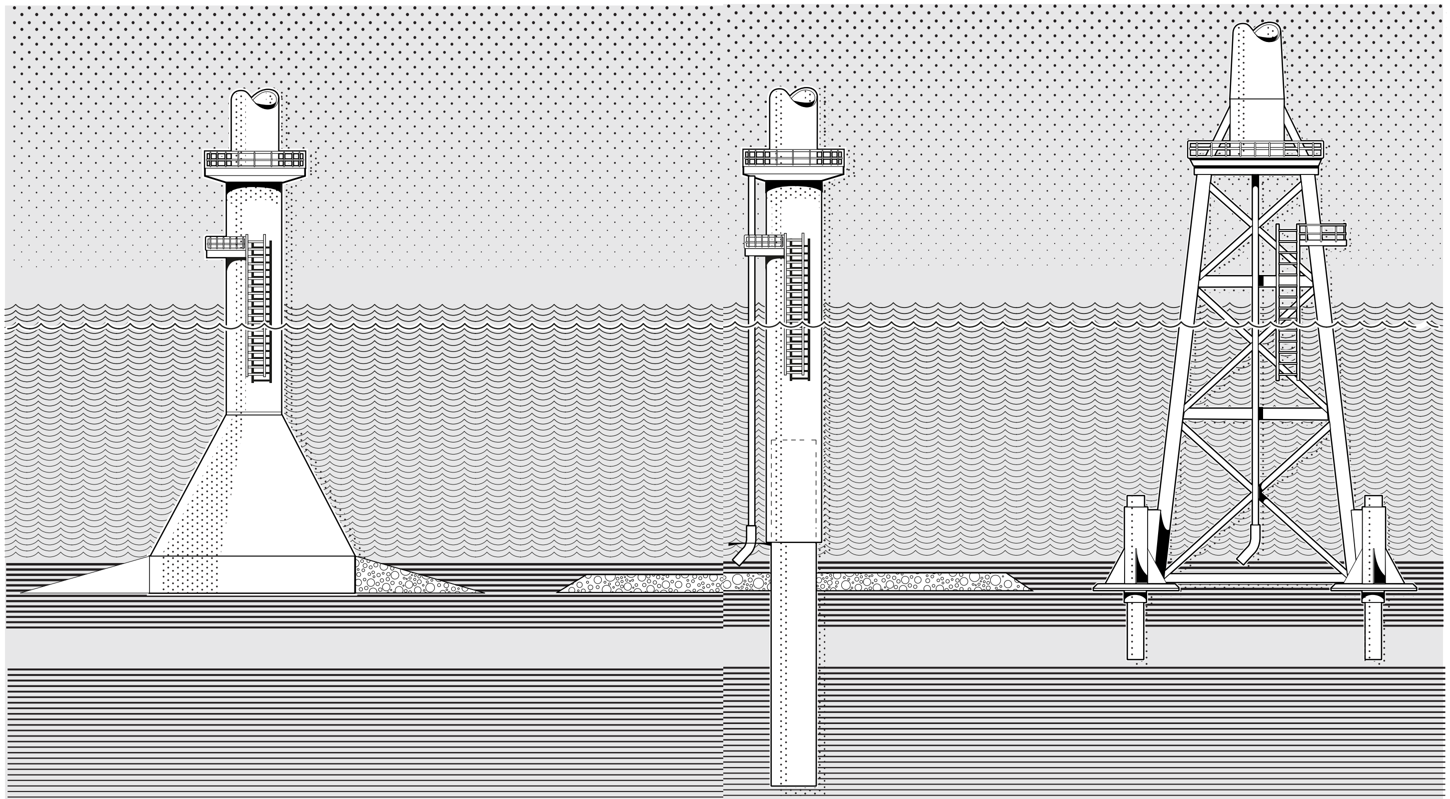
Monopiles can be deployed in water depths of up to 25-30m. They are generally reliable, and are easy and cheap to fabricate and install. A further technological advancement is the XL (extra-large) monopile allowing for greater turbine and tower weights.

They are not without their problems, however. The monopiles require noisy piling, which can lead to installation restrictions. And they need protection from moving rocks and other material on the seabed, known as scour protection.

An alternative to monopoles are steel "jacket" foundations. These are typically four-sided A-shaped structures, made of low-diameter steel tubes, resting on piles and typically weighing 500–600 tonnes.



A wind turbine atop a jacket-style foundation, which typically weighs around 500-600 tonnes. This type of foundation is secured to the seabed by massive steel pins.



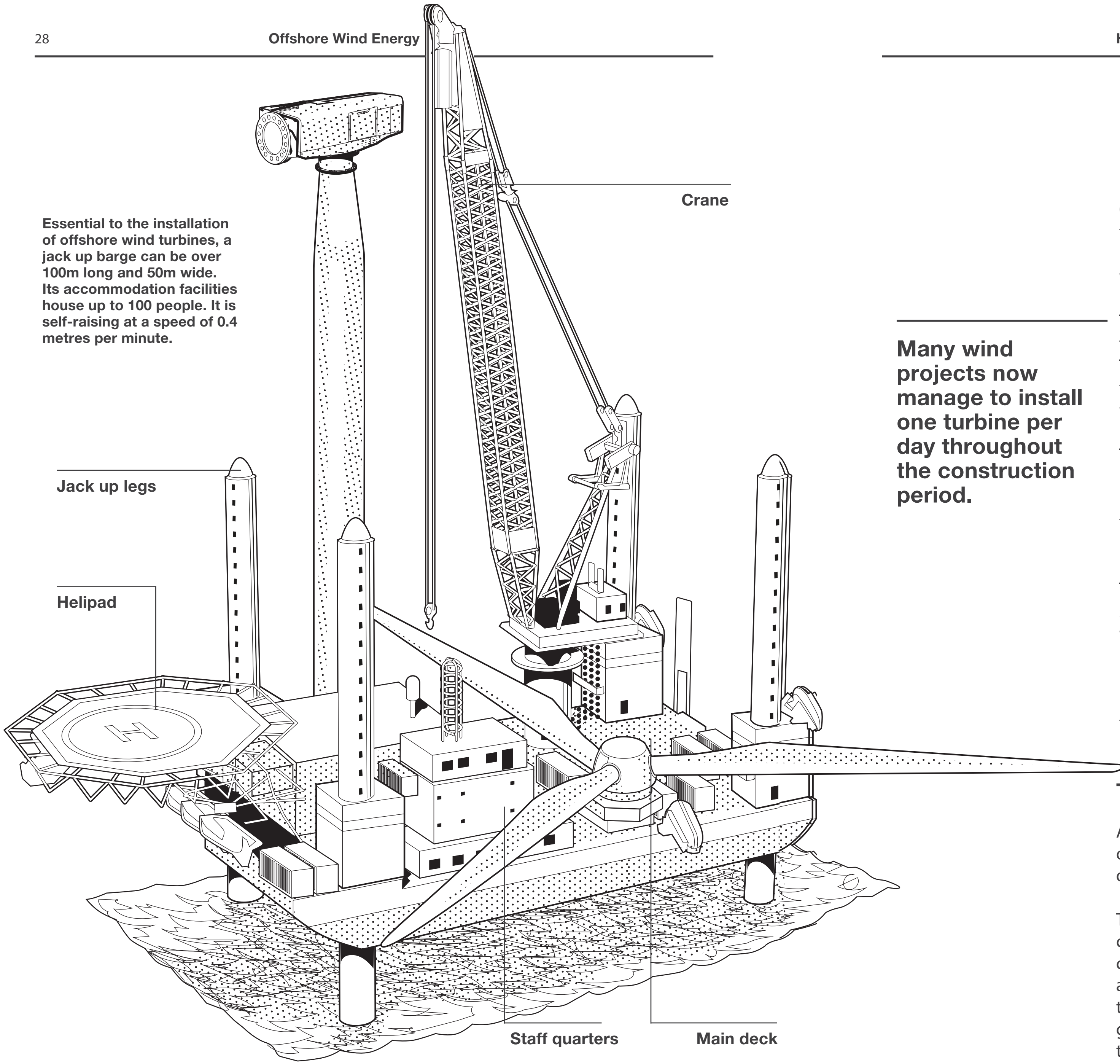
The three main types of foundations used in the construction of offshore wind farms. From left to right: gravity base, monopile, and jacket.

Jacket foundations are extremely strong and have been used successfully for decades in the offshore oil and gas industry. However, they are time-consuming to build, with their multiple welded joints, and each individual wind farm requires custom-made jackets to match its seabed conditions and water depth.

During transportation jackets cannot be stacked, and therefore use up more space on transport vessels, adding to installation costs. All of this means that jackets are considerably more expensive than monopiles. Much industry discussion has revolved around the need to industrialise and reduce costs of jacket production as wind farms move into deeper waters.

Other types of foundations have also been tried, such as gravity-based structures and so-called suction buckets, neither of which require piling. Gravity-based structures can be made of concrete, which is a cheaper material than steel. They are then towed and sunk into position.

Currently, gravity-based and suction bucket foundations are very much niche solutions. But, research and development aimed at industrializing these technologies for offshore wind construction is ongoing, and has resulted in refinements to the concept, for example, the 'mono-bucket'.



Essential to the installation of offshore wind turbines, a jack up barge can be over 100m long and 50m wide. Its accommodation facilities house up to 100 people. It is self-raising at a speed of 0.4 metres per minute.

Installing the turbines

Once the monopiles or jackets have been installed, it is time to install the turbines themselves. This involves the use of very large installation vessels, known as jack-up vessels.

Many wind projects now manage to install one turbine per day throughout the construction period.

These self-propelled vessels manoeuvre themselves into the right position using dynamic positioning systems. They then use legs to lift themselves out of the water, so that giant cranes can perform the lifts on a stable base, without any influence from waves or swell.

The turbine towers are then lifted into place, followed by the nacelle (which houses the turbine's gearbox, if it has one, generator, and other equipment) and finally the three blades, each of which, in modern turbines, can be up to 80m long.

The difficulty and speed of installing wind turbines are still heavily dependent on weather conditions, with high winds, for example, complicating the installation of rotor blades. However, there have been steady improvements over the last decade, and many wind projects now manage to install one turbine per day on average throughout the construction period.

Taking the electricity onshore

A major engineering and cost issue when building offshore wind farms is how to transport the electricity onshore and feed it into existing power networks.

The individual turbines in a wind farm need to be connected to an offshore substation by inter-array cables, in order to centralise the electricity generated and convert it to the right frequency. This substation then needs to connect to the shore with one or more giant export cables, which weigh thousands of tonnes, making them the heaviest items in an entire wind farm.

Construction of a substation at the Humber Gateway project. The jack-up barge's crane lifts the substation components into place.

The cables are normally laid by a special type of vessel that both ploughs a trench on the seabed and lays the cables in it. The process has not proved to be without its problems over the years. A common hitch has been cable "kinking", which can severely restrict power flow and requires expensive remedial action. In addition, offshore wind farms often require new substations to be built onshore, in order to feed the power into the national grid and this entails its own planning complications and costs.

As wind farms move further away from coastlines in order to harvest the best winds, operators are increasingly being forced to look at using High-Voltage Direct Current (HVDC). Although this entails higher costs, it is necessary because of the power losses associated with using alternating current (AC) technology, which makes transporting power over distances of over 50 to 70km impractical.

The use of HVDC was pioneered in Germany, where a series of huge HVDC converter stations was built to centralise and export power from projects in the North Sea. In the UK, the next generation of projects being built as part of Round 3 is also turning to HVDC.

The need to build offshore converter stations/substations is a major engineering challenge. The largest substations are the size of a football pitch, at 90 x 60 metres, and the weight of the Eiffel Tower, at 10,000–12,000 tonnes!

This has led to a rethinking of substation design in recent times. German engineering firm Siemens, for example, is pushing the concept of the Offshore Transmission Module (OTM), a stripped-down, lightweight unit that can be directly attached to a wind turbine. Siemens says that the new concept could be 40% cheaper than installing a traditional substation.

Floating offshore wind

For supporters of offshore wind energy, floating turbines are a particularly promising development. Floating structures could be used to deploy wind turbines in very deep waters, and could eventually become as economical as grounded structures. The technology could open large swathes of the world's oceans, currently too deep for conventional foundations, to energy development.

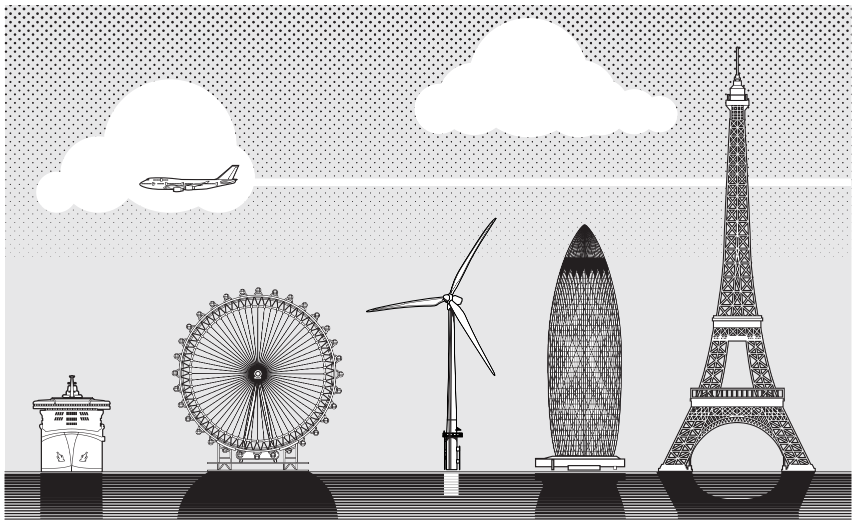
A large research effort has been put into the technology, with the aim being to create a stable platform that does not affect turbine performance. The first full-size floating turbine was built in Norway in 2009, while the second was deployed off Portugal in 2011. In the UK Statoil has begun construction of its Hywind project, a 30MW floating wind farm at Buchan Deep, 25km off the North East Scotland coast.

Floating turbines could open large swathes of the world's oceans to energy development.

In recent years, Japan has committed large resources to developing floating offshore wind, due to the deep waters around its coastlines, and is developing a large-scale pilot floating wind farm offshore at Fukushima, in the north-east of the country.

Floating wind technology allows wind turbines to be towed out to site from harbour, limiting the need for specialised installation vessels. They could be deployed so far from shore as to dispel any aesthetic objections, and decongest busy coastal waters. In terms of engineering it is a challenging technology, but one with an enormous potential.

Section 5. Mega machines—offshore wind technology



One of the new generation of offshore 'super turbines', the MHI Vestas V164 has 80m blades, the equivalent of nine double decker London buses. Each blade weighs 35 tonnes and the swept area of 21,124m^2 is larger than the London Eye. The nacelle is 20m long, 8m wide and 8m high, weighing approximately 390 tonnes. One rotation of the blades at rated power generates enough electricity (13,3kWh) to supply the average UK household for 29 hours.

The first offshore wind turbines were converted versions of onshore turbines. As time went on, however, companies began to build turbines specifically for the offshore market. There are several key issues in the design of offshore wind turbines.

Firstly, offshore, size matters. Because of the relatively inelastic costs of installing offshore—the need for foundations, vessels, underwater cabling and so on—it makes sense to try to maximise the size of the individual turbines in a wind farm. This has led to a steady rise in the size of turbines. The 450kW turbines installed at Vindeby, the first offshore wind farm in the world, had a total or blade tip height of 52 metres. The 8MW MVOW turbines being installed in 2016 at Burbo Bank will have a tip height of 187 metres.

As a further illustration of how the turbine market has evolved, the average size of a wind turbine in offshore use is currently around 4MW; in onshore wind, the average size is around 1.6MW.

Current average rating of an offshore turbine is 4MW. Onshore it is around 1.6MW.

The second issue influencing design is reliability. Offshore wind turbines operate in a much harsher environment than onshore wind farms, buffeted by high wind speeds and facing the threat of corrosion from salt water. And at the same time, the turbines are located far from shore, and weather conditions can make accessing them to carry out maintenance difficult. Mistakes made in the design and production process will invariably work out to be extremely costly.

For this reason, offshore turbines are designed to be extremely rugged and reliable, in order to minimise the amount of maintenance work that needs to be carried out, and are "weatherised" to provide extra protection for internal and external components.

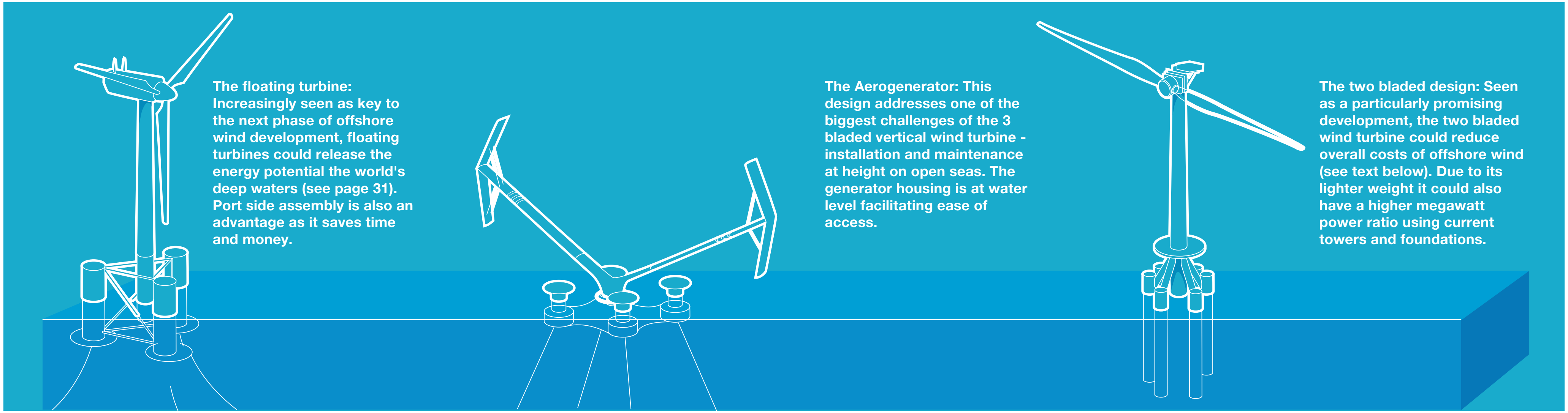
Gearboxes vs. direct drive turbines: The costs

One cause of mechanical failure historically has been the gearbox, which is used to increase rotational speed from a low-speed rotor to the electrical generator. The gearbox is one of the most complicated parts of the turbine, and the one with most mechanical parts.

This has led some companies to turn to so-called "direct drive" designs. A direct-drive turbine has no gearbox. Instead, a single large rotor with permanent magnets spins at the same speed as the turbine blades and transmits power directly to the generator. Historically, the downsides to this approach have been an increase in weight and cost because of the large rotor size, the need for a bigger generator, the cost and risk of scarcity associated with permanent magnets, and more complex power electronics.

However, designers have taken steps to address these issues. For example, Siemens has switched from using

Innovative and unconventional turbine designs



geared designs to using direct drive in its new models, such as the 6MW turbine that is being deployed in the latest wind farms in UK waters. It has introduced a series of innovations that have allowed it to dramatically reduce the weight of the entire turbine nacelle to a level less than geared models.

In recent years, a compromise solution has emerged: a simplified “mid-speed” gearbox that significantly reduces the amount of mechanical parts in the turbine by dispensing with the fastest speed stage in a typical gearbox. The idea of this concept, used in successful turbine models produced by companies such as MVOW and Adwen, is a reliable and robust turbine, but at a lower cost than direct drive.

Unconventional turbine designs

All of the offshore turbines in commercial operation around the world today have a foundation, three blades, a tower and a nacelle. However, innovation continues apace. The illustration above shows three current prototypes addressing some of the challenges of offshore wind development. One of the simplest alternative ways to reduce the cost of wind power would be to build two-bladed, rather than three-bladed, machines.

Proponents argue that this would save around 20% of construction and installation costs. The idea is not new, having been widely tried onshore in the 1980s. One reason they were unsuccessful onshore is that having two blades means that they have to spin faster, causing more noise. However, this is not a problem offshore.

In recent years, several new companies have revisited the idea and now have prototypes in place. The most common approach has been to spin the rotor 180 degrees round, to face downwind rather than upwind. One of China’s biggest turbine manufacturers, Ming Yang, is testing a 6MW turbine designed by Germany’s Aerodyn at the Rudong testing area, and plans another in Norwegian waters. Dutch wind technology developer 2-B Energy is planning to install two downwind, two-bladed 6MW machines in Scottish waters. And in Japan, Hitachi and Fuji Heavy Industries have teamed up to test a 2MW model.

However, until a big two-bladed model has been shown to operate successfully over time at an efficiency level close to three-bladed turbines, the jury is still very much out.

MVOW blade technician working on a blade for the V164-8.0MW wind turbine, atthe Isle of Wight facility

The turbine manufacturers

A number of manufacturers have been involved in the offshore wind turbine scene over the last two decades. In Section 6 we will cover MVOW. Here are some of the other most active at the time of writing.

Adwen

Adwen is a joint venture, formed in March 2015, between state-owned French nuclear firm Areva and Spanish-owned wind turbine manufacturer Gamesa. In 2013, Areva announced it was working on an 8MW turbine to supply contracts won as part of the second French offshore wind tender and UK Round 3 projects. Gamesa began work on a 5MW turbine in 2010, and announced plans to design and manufacture a 7MW model (since cancelled). The joint venture will aim to commercialise 5MW and 8MW offshore wind turbines.

Alstom

French industrial group Alstom began testing a 6MW direct drive turbine known as Haliade in early 2012. An offshore prototype was installed off the coast of Belgium in 2013. Alstom has won orders for the turbine in the first French tender round and has built manufacturing facilities in Saint-Nazaire and Cherbourg. It also won an order to supply the Deepwater Wind project in the US. In 2014, Alstom agreed to a $17bn acquisition offer by US industrial giant General Electric (GE), itself a major wind turbine manufacturer.

Senvion

Senvion—formerly known as Repower—was one of the early leaders in the offshore field. In 2006, it deployed the world's first 5MW offshore turbine at the Beatrice demonstrator project off Scotland. The 5MW—and an updated 6MW model—were subsequently used in a number of projects in the UK, Germany and Belgium. In 2009, the company was bought by Indian wind turbine manufacturer Suzlon. In 2015, Senvion was bought by US private equity group Centerbridge for $1.2bn.

Siemens

Siemens is the current market leader in the offshore wind turbine market, with around 65% of cumulative installations at the end of 2014. The company bought Danish offshore pioneer Bonus in 2004 and built upon its experience to create its highly successful 3.6MW turbine, which was the dominant model for a number of years. It subsequently created a 6MW direct-drive model, which is being deployed in some of the latest UK projects, and for which the blades will be built at the company's new blade manufacturing plant in Hull.

Section 6. A UK manufacturing case study: MHI Vestas Offshore Wind (MVOW)

MVOW is an offshore wind turbine original equipment manufacturer (OEM) with a significant presence in the UK, including an established UK manufacturing operation.

At June 2016, MVOW is the only OEM operating a manufacturing facility in Britain for a major offshore wind turbine component. The facility is a great example of how the formidable challenges in harnessing offshore wind as a power source are driving innovation, while generating employment and accelerating cost reduction.

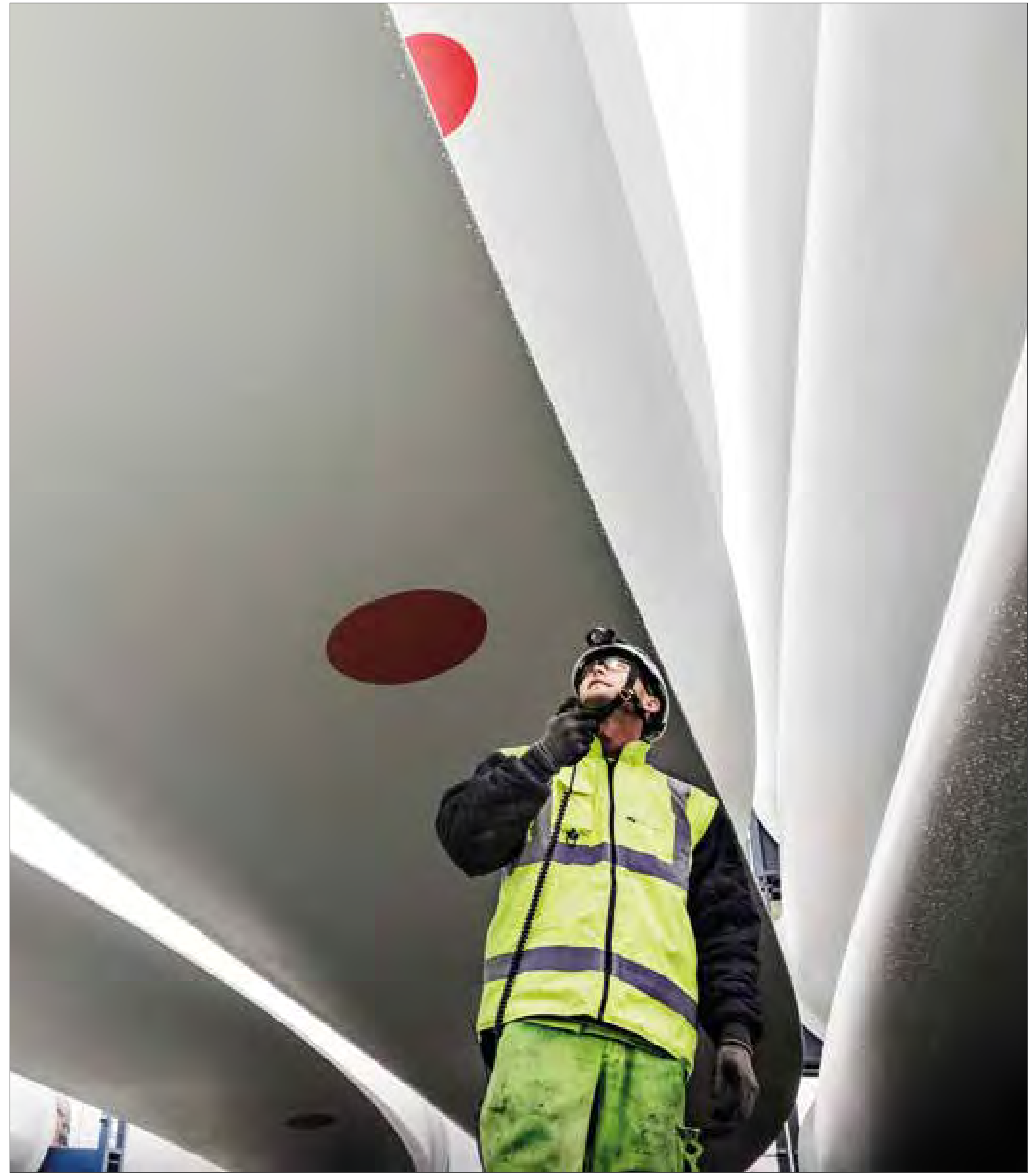
Isle of Wight: The Offshore Wind Blade Factory

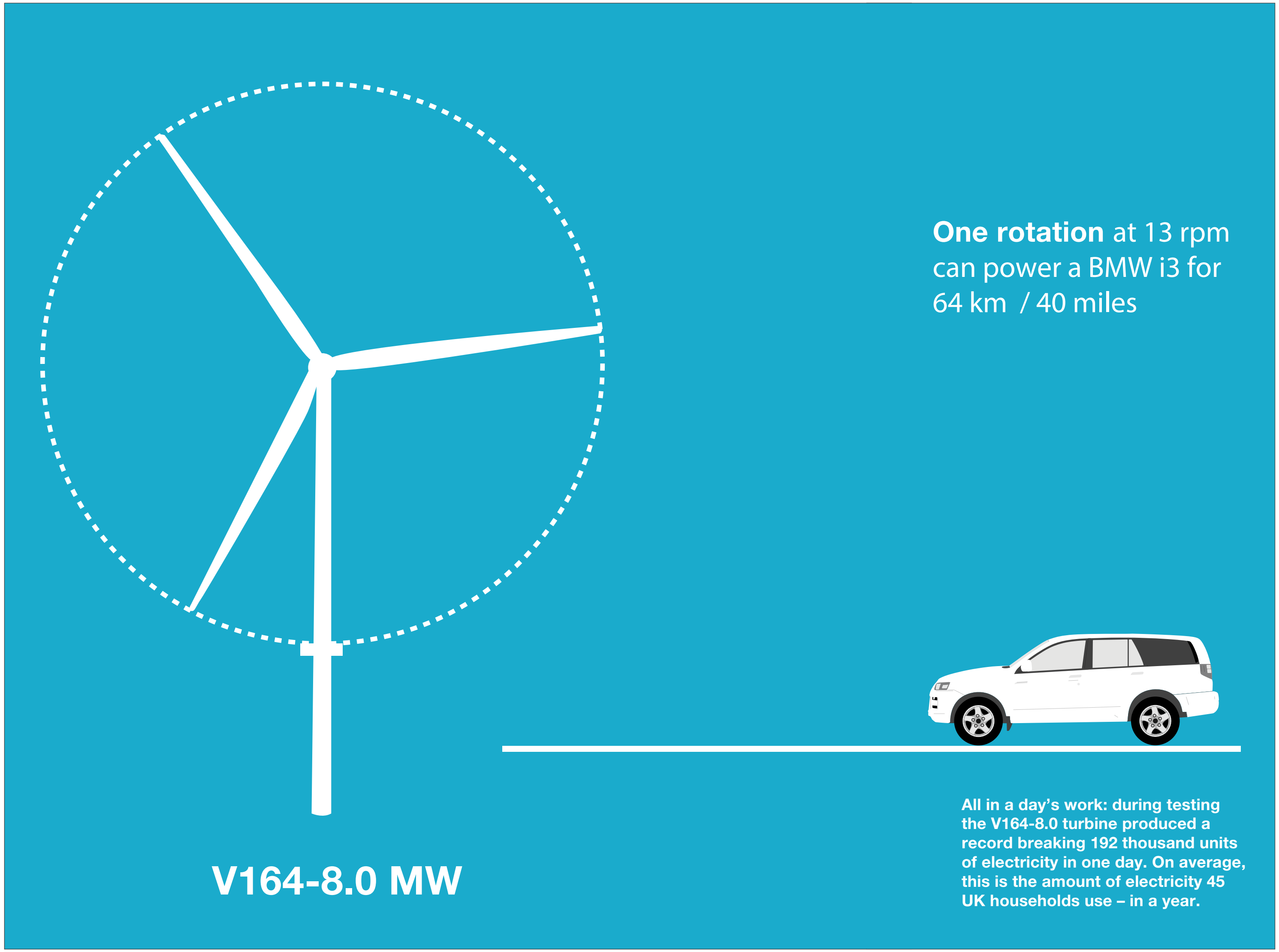
MVOW manufacturing hub in the UK has been located on the Isle of Wight since May 2015. It follows a longer tradition of wind energy manufacturing on the island going back to the 1990s. The facility consists of two halls, 170 metres long and 50 metres wide, one for testing and verification, and the other for blade production.

Mitsubishi Heavy Industries (MHI) and Vestas Wind Systems announced an alliance in 2013. Their aim was the development of an offshore 8MW super turbine. This provided most of the direct impetus to create 270 jobs on the site. Already the Isle of Wight facility had orders for Dong Energy's 258MW Burbo Bank project and the 330MW Walney extension project off the coast of Liverpool Bay in the UK. There is also the ambition to export to offshore projects outside the UK.

As for the types of positions created, around 230 are blade or component technicians, operators, or production support staff, with the rest being team leaders, finance officers, HR officers and engineers.

Stacked up and ready to go: Wind turbine blades are stacked and ready for transport to site, at the MVOW pre-assembly facility in Esbjerg. They are arranged in a 'blade stacker' system, 3 blades on top of each other, to make it efficient for vessel transport.





All in a day's work: during testing the V164-8.0 turbine produced a record breaking 192 thousand units of electricity in one day. On average, this is the amount of electricity 45 UK households use – in a year.

The Isle of Wight factory has also benefited the wider supply chain, another hallmark of offshore wind manufacturing. The hydraulic pitch system in the blades, for example, is manufactured at Bosch Rexroth in Wakefield, West Yorkshire, which in turn has helped the company grow a custom production line at the Wakefield facility.

There are many other local suppliers too, such as Incom, MSA Manufacturing, Global Wind Turbine Services, and Gurit who are all located on or close to the Isle of Wight, who supply materials and components into blade manufacturing. Overall these materials, components, and services, designed and manufactured by hundreds of people across the UK, are being assembled as part of a cutting-edge machine, the V164-8.0MW wind turbine.

V164: The offshore 'super-turbine'

The Isle of Wight factory currently produces some of the longest wind turbine blades in the world. At 80 metres, nearly the length of a football pitch, the blades will serve the powerful V164-8.0MW offshore wind turbine.

This colossal machine is one of the most powerful currently operational models in existence. In October 2014 it smashed the world record for the most power produced by a wind turbine, at peak production delivering 192,000 kWh in a 24-hour period.

Size magnitudes are driving down the cost of energy.

The turbine has also been selected for the 400 MW Horns Reef 3 project in Denmark, a move which has galvanised the UK offshore industry for two reasons: it is the first example of a UK offshore OEM facility exporting to outside markets, and the new project will be 30% cheaper than an equivalent 400 MW project from 2011.

The swept area of the machine, meaning the area covered by the rotation of the three blades, is just over 21,000 m^2, larger than the London Eye.

The nacelle, or the housing for the generator at the top of the turbine tower (see page 5 for parts of the turbine), 20 metres long, 8 metres wide and 8 metres high, and weighs approximately 390 tonnes. This is even more impressive considering that such weight loads are sitting on top of a tower over 100 metres tall, or 140 metres in the case of the prototype, tested at Østerild in Denmark. In fact, the total height of the Østerild prototype turbine, from sea level to tip height, is 220 metres.

As we have already seen, such size-magnitudes are driving reductions in the cost of energy for two main reasons: on a per-project basis, offshore wind farms comprised of 'super-turbines' require fewer foundations and service visits, while producing more energy. MVOW sees that such economies of scale in turbine design will be the chief contributors to driving down cost of offshore wind to around €85/MWh by 2025.

Belfast Harbour: Further industrial growth

MVOW industrial strategy foresees £200m worth of investment and the creation of up to 800 jobs.

In terms of industrial growth the decision to manufacture blades on the Isle of Wight is the first part of a wider industrial strategy in the UK which is expected to result in up to £200m worth of investment and the creation of up to 800 jobs. The next step in the strategy is the development of a pre-assembly site in Belfast Harbour.

The 20-hectare site was taken over by MVOW on April 1 2016, with the aim of having a base for the Burbo Bank and Walney Extension projects. It has been fitted with a main installation crane and has started receiving components for the Burbo Bank Extension project in May 2016.

As with the development of the V164 turbine, the investment in the site is expected to eventually contribute to reducing project costs. The premise is that spending more times onshore to assemble turbine components minimises the more expensive time spent offshore, while also reducing construction risks. Onshore pre-assembly reduces reliance on the weather, thus driving down installation costs, the amount of stoppage time, and health and safety risks.

The synergy of the Belfast Harbour pre-assembly site with the Isle of Wight manufacturing facility positions MVOW as a key player, and paves the industrialisation path to build-out post 2020. The UK government has signaled that there is potentially a further 4GW of offshore wind capacity up to 2020, with other EU countries continuing to develop their own resources, particularly in the North Sea.

The MVOW industrial facilities, coupled with a world-leading offshore wind turbine, the V164-8.0, will help the UK move from being the world's leading market for offshore wind, to an offshore wind industrial force.

Section 7. Cost reduction: A prerequisite for growth

Seasoned offshore wind watchers would agree that one topic, above all others, has been dominating the sector since around 2010. This is the topic of cost reduction. To understand why this is the case, let us briefly summarise some of the points made in the previous chapters.

We have seen that from a standing start in 2001, offshore wind in the UK has grown to be one of the major contributors to the nation's electricity supply. The estimate is that by 2020 it will contribute around 10% of electricity, and this could grow to around 15% by 2025. To put this into context, the contribution of nuclear power in the UK, which has been around since 1956, varies between 15% and 20%.

We have also seen that this growth has been facilitated by the advancements made both in offshore wind turbine technology and the construction of offshore wind farms. These advancements have resulted not just in bigger, more robust machines, customised for the harsh offshore environment, but also in accelerated offshore deployment rates. Once construction starts on a modern offshore wind farm, it is possible to install one modern 'super turbine' every day during construction season.

In a nutshell, the technology can be deployed at scale, quickly and make a real difference. But it is also a young technology and, as such, has relied on state support, in anticipation of full industrialization. Traditionally, in Northern Europe, its core market, support for offshore wind has taken the form of a premium payment for electricity from offshore wind farms.

The debate on cost

The debate on the technology has shifted from 'can offshore wind deliver' to 'at what cost'. As the sector grew, it became clear that for offshore wind to realise its full potential, it would also have to be able to compete on price.

Competitiveness means both decreasing reliance on state support, and price parity: first with other renewable and low-carbon energy technologies, and then, in the longer term, with conventional sources like gas. In the rest of this chapter we will explore how the costs of offshore have been falling to meet these aspirations.

Ambitions on cost reduction:

The UK Government would like to see levelised cost of electricity (LCOE) from offshore wind come down to £100 per MWh by 2020 and then to £85 per MWh by 2026. The industry is even more ambitious: DONG Energy has an ambition to reach 100 Euros per MWh (approx. £85 in current exchange rates) by 2020 and Statkraft has predicted costs as low as £53 per MWh by 2030.

Reducing costs: the volume dilemma

Offshore wind is currently more expensive than onshore wind. This is not surprising given that there are around 4,000 offshore wind turbines globally, compared to 260,000 onshore. Onshore wind has been able to benefit from decades of volume-driven cost reduction, which is something that is now starting offshore.

This has caused something of a dilemma for policy makers and the industry. If the industry is to reduce costs it needs to deploy at scale. But initial deployment at scale needs to be funded at a premium as the industry has not yet reached full industrialization. This has resulted in a flurry of activity by the industry to identify the cost reduction potential of the technology, while policy makers have started to ramp down support.

Progress so far on cost reduction

The strong focus on cost reduction is now yielding results. Costs have fallen by 40%, with industry reducing costs earlier than expected. Further reduction will need to come from the innovations in 'balance of plant', such as foundations, cables and substations. But the industry consensus is that the impetus to deliver such improvements will only come with greater visibility of future deployment rates, or volume.

Experience of developing offshore wind farms at scale has given industry confidence in its ability to keep delivering cost reductions. DONG Energy has an ambition to reach 100 Euros per MWh (approx. £85 in current exchange rates) by 2020. Statkraft has predicted costs as low as £53 per MWh by 2030. The UK Government has set a target of £85 per MWh by 2026.

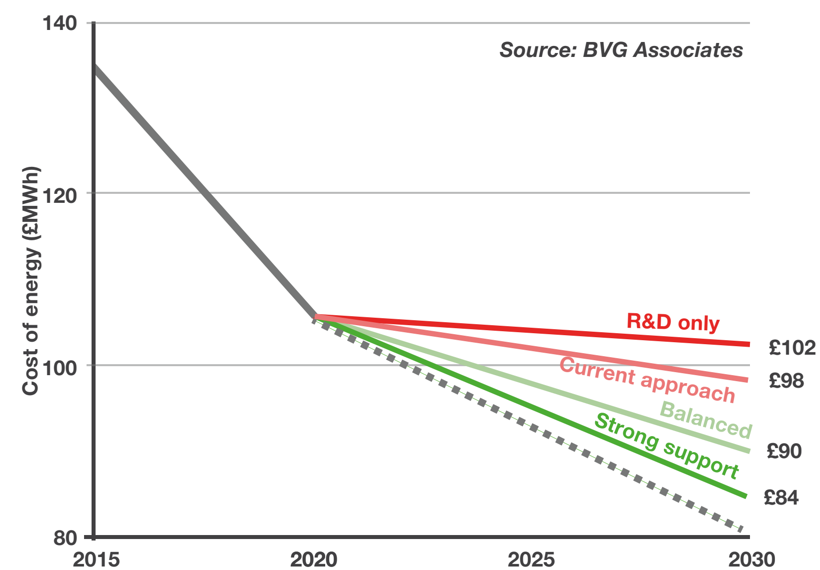
Costs have fallen by 40%, with industry achieving reductions earlier than expected.

Achieving these cost reductions will make offshore wind cheaper than nuclear power and competitive with new gas plant. And this will be achieved with increased economic benefits for companies across the UK.

The work of the Task Force was continued by the Offshore Wind Programme Board (OWPB). Its progress report on delivering a 30% reduction by 2020 has shown an industry ahead of its target. Between 2011 and 2014 and 11% reduction was seen, largely due to an earlier than expected adoption of larger turbine models.

In conclusion, it is worth noting two things: the timescale for cost reduction by the various industry parties is given in years rather than decades. There is a great deal of confdence that cost reduction has already kicked in, and that it will deliver signifcant savings in a relatively short time period. The second is that the once dim and remote prospect of cost parity with other renewable technologies, let alone conventional power sources, is now being openly discussed, by an increasingly confident and ambitious industry.

In its 2015 report for the Committee on Climate Change, BVG Associates estimated that 'strong support' for offshore wind could bring costs down to £84 per MWh by 2030. Supporting R&D only, or the current/balanced approach would not drive down costs as quickly. Strong support means Governments across the EU committing to between 4GW and 5GW of new offshore wind capacity per annum.



Section 8. How many jobs does offshore wind create?

Jon Beresford, Offshore Wind Operations Manager for E.ON. An offshore wind operations manager's job is to ensure that the day-to-day operations run smoothly and that the turbines are working as well as possible. This involves managing teams of engineers, meeting suppliers, and tackling problems as they arise.

The building of large-scale offshore wind farms off the coasts of Britain and Northern Ireland requires the development of a whole new supply chain. This in turn requires building new manufacturing capacity and creating new services. And this means jobs.

In 2008, when RenewableUK commissioned its first wind industry job count, the sector employed around 700 people. Latest jobs figures put total offshore wind employment in the tens of thousands. People work in the construction and installation of projects, planning and development, operations and maintenance, manufacturing and transport, and other support services.

However, realising the potential of offshore wind for manufacturing and employment requires the UK capturing a greater share of the supply chain. Currently, only about 40% of the lifetime costs of operational wind farms are spent domestically, as most of the major components—particularly big-ticket items such as wind turbines and foundations—have been imported, often from Denmark and Germany.

Companies active in the offshore wind sector are supportive of using more local content, both for cost reasons and because they recognise that the UK and its people need to benefit from the sector, through economic growth and jobs, if it is to continue to enjoy political support.

There are already positive signs that manufacturing is starting to shift to the UK in order to take advantage of proximity to the big wind farm projects. As the supply chain develops, the UK is a prime location from which to supply the wider European offshore wind market, which has the potential for over £50bn of non-UK contracts out to 2020. The UK has already supplied cables and foundations for German projects and offshore substations to Belgium. With MVOW now manufacturing blades on the Isle of Wight, and with the Siemens blade factory in Hull now under construction UK content and export will increase.

With over a decade of deployment and the largest capacity of offshore wind in the world, UK companies are in a unique position to commercialise the expertise they have built up in the sector. There are a number of emerging markets that will present growth opportunities for UK companies in the coming years, including the US, China, and Japan. Further prospects include South Korea, India, Canada and Taiwan.

Some of the jobs in offshore wind

Offshore wind turbine technician

Usually working for the turbine manufacturer, in charge of maintaining the blades and the components within the nacelle, as well as the electrical systems exporting power from the turbine.

Marine biologist

Fulfils a key role in designing and developing the wind farm to make sure it is safe for marine and avian species, compiles environmental assessments and monitors long term operational impacts.

Investment analysts

Employed by large investors or working as a consultant, advises on project cost, viability, construction risk, long term returns and ensures the offshore wind farm is a sound investment proposition.

Installation vessel captain

Offshore wind farm construction requires precise co-ordination of large vessels on open seas to a distance of centimetres – this is where an experi-enced captain has a key role to play.

R&D expert

With a background in engineering or applied science, serves at the cutting edge of research into new offshore wind materials, devices, components or technical procedures.

What does the UK offshore wind supply chain look like?

Offshore turbine manufacturing

For a number of years, the UK has not produced its own wind turbines. Now, with the growth in the offshore sector, manufacturing is returning. The pipeline of projects in the UK to 2020 alone will require 800–1,000 wind turbines—this is around 50% of the European market.

Latest jobs figures put total offshore wind direct and indirect employment in the tens of thousands

MVOW started producing the giant blades for its V164 8MW turbine on the Isle of Wight in May 2015, the first part of a wider manufacturing strategy to create up to 800 jobs across the UK. Siemens has committed itself to manufacturing turbines on the Humber and is currently constructing nacelle and service facilities along with Associated British Ports (ABP), and a separate blade manufacturing facility. These will be up and running by the end of 2016.

Other companies, including Alstom and Adwen, have also said they would set up manufacturing facilities in the UK if there is sufficient demand for turbines, and have engaged in talks with ports and landowners.

Foundations

The offshore wind market continues to generate high demand for monopiles and transition pieces, and investment in new or existing plant could deliver these competitively from the UK. The UK also has the capability to deliver jackets and secondary steel, with opportunities for partnership and investment to deliver serial jacket production.

Offshore turbine towers

Existing European facilities do not have the capacity to deliver the volume of offshore towers required by the market – new investment is required. The UK offers significant logistical advantages, due to the challenges and costs of transporting towers to the locations where they will be installed.

Cables

The UK is increasingly competitive in cable manufacture and has a strong track record of supplying interarray cables to the domestic and EU markets. As an example, JDR Cables, with UK facilities in Hartlepool and Littleport, is one of the world's leading suppliers. In 2014 alone it won contracts to supply RWE Innogy's Nordsee One project and Vattenfall's Sandbank project, both in German waters. Its projects in the UK have included London Array and Greater Gabbard, two of the country's largest completed projects to date.

Substations

The UK project pipeline requires an estimated 13–15 offshore substations by 2020. UK fabricators have a long history of building platforms for the offshore oil and gas sector, and a track record in supplying projects in the UK and wider EU markets.

A study carried out on E.ON's Robin Rigg wind farm showed that 86% of expenditure on O&M was made locally.

Operations and maintenance

As more and more wind farms come into operation, there will be increasing need for skilled personnel to carry out operations and maintenance (O&M) activities. A study carried out on E.ON's Robin Rigg wind farm showed that 86% of expenditure on O&M was made locally, compared to less than 40% for the construction of the wind farm, and a large proportion was made locally.

Other services

The offshore wind industry creates demand for a large number of other services. Some are to do with the construction and operation of the wind farms, such as the provision of transport and accommodation services for people working on the projects.

As an example, a number of UK companies are supplying workboat services for the offshore industry: from companies that operate the big jack-up vessels that we saw in Chapter 4, such as Seajacks and MPI Offshore, to companies that supply smaller high-speed vessels to transport workers to and from the wind farms.

Other services are less operational, involving planning, strategy, public engagement and finance. By the time a project has gone from idea to operation, it will have had input from experts on the local environment and wildlife, on site planning and logistics, public relations and legal experts, economists, and many more people, some of them directly employed by developers and others employed by consultancies or small businesses.

The future of offshore wind is global: from the EU, where around 40% of the population lives in coastal regions, to the US, China and Japan, which host some of the biggest coastal cities in the world, offshore wind is increasingly seen as the answer to solving the energy equation: producing ample, indigenous, carbon free energy, close to industrial and population centres - with a minimal land footprint.

Section 9. How big a role will offshore wind play?

The year is 2050. In the Thames Estuary, London Array is replacing its 20MW offshore wind turbines with a set of next-generation 50MW machines. At the repowering ceremony, ushering in another 50 years of operation (and making it, in one reporter's memorable phrase, 'the world's first 22nd century wind farm') the London mayor and the Prime Minister welcomed representatives of the New York and the Tokyo Arrays. The speeches hailed the wind farm as not just one of the main contributors to reaching the UK's climate change targets (as set out decades ago in 2008's Climate Change Act), but also, thanks to it being plugged into a trans-European super-grid, as one the country's chief energy exporters.

How plausible is this scenario? Perhaps more plausible than appears at first sight. We have seen that in the 15 years since the UK's first offshore wind farm pilot project was constructed, the industry has grown to supply around 7% of the UK's total power supply. With 10GW of capacity expected by 2020. With 10GW of capacity expected by 2020 offshore wind will provide approximately 10% of the UK's supply. There is no reason why growth in the 2020s and beyond could not deliver an even larger contribution to the nation's power supply. In fact, current levels of funding signal that the UK could have around 15GW of offshore wind by 2025.

Innovation and the offshore energy economy

In terms of innovation, an EU study on the potential for wind turbine scalability has stated that current limits of materials science allow for turbines of up to 50MW in capacity. Just 2,000 such machines (and the UK currently has close to 2,000 turbines) would supply all of the UK's electricity, and leave some for export.

Making a conservative assumption that capacity will reach 10GW by 2020, offshore wind will provide approximately 10% of the UK's supply.

Looking closer at the present, there are a number of factors that could hasten the development of an offshore wind 'energy economy'. The Climate Change Act committed the UK to an 80% cut in carbon emissions by 2050, and made the UK the first country to set itself legally binding carbon budgets as a means to monitor progress to this target. The latest budget commits the UK to emissions reductions of 50% on 1990 levels by 2025.

Secondly, there are restrictions on the ability of other sources to supply power on the scale that is needed before older power stations close down across the next decade.

The main reason for confidence about offshore wind's future role is its demonstrable ability to bring costs down. Already costs have fallen by 40% and are set to continue falling. Innovation in the industry means we are seeing cost reductions more in keeping with consumer electronics than major infrastructure.

Reaching the tipping point

Finally, there is every reason to suppose that offshore wind will become the most economical way for the UK to add new power capacity on the scale that it needs. Offshore already compares well to nuclear, its closest rival in terms of being able to add power in large quantities. Finally, there is every reason to suppose that offshore wind will become the most economical way for the UK to add new power capacity on the scale that it needs. Onshore already compares well to nuclear, its closest rival in terms of being able to add power in large quantities.

As the industry grows in scale and efficiency gains are made, experts expect a "tipping point" to be reached, leading to significant further reductions in costs. And that is without factoring in any new "game-changing" technological advances that could be deployed.

Conclusion: The future

The offshore wind industry represents an opportunity for the UK to rebuild its power sector around a clean and inexhaustible energy resource. It also provides a chance for the country to build on its heritage of maritime engineering and large-scale manufacturing.

But it is also worth remembering that the industry will only be successful if it can make rapid and substantial gains on efficiency and cost. This is necessary in order to retain public and political support. If it rises to the challenge, the UK will see the build-out of further offshore wind capacity and will have this as one of our biggest sources of power for decades to come.

As the world continues its search for a clean energy matrix, the offshore wind industry will become truly global. The UK, as the world pioneer in the sector, is sure to continue to play a big role in its future.

MHI VESTAS OFFSHORE WIND

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RenewableUK is the UK's leading not for profit renewable energy trade association. Our vision is for renewable energy to play a leading role in powering the UK.

MHI Vestas Offshore Wind is a joint venture between Vestas Wind Systems A/S 50% and Mitsubishi Heavy Industries (MHI) 50%. MVOW entered the UK offshore market in 2004 (as Vestas) and has installed almost 1 GW of wind turbines. MVOW has over 200 employees in the UK working within the production, sales, and service organisations.