THE CROWN ESTATE

A Guide to an Offshore Wind Farm

Published on behalf of The Crown Estate

THE CROWN ESTATE

The Crown Estate

The Crown Estate owns virtually the entire sea bed out to the 12 nautical mile territorial limit, including the rights to explore and utilise the natural resources of the UK continental shelf (excluding oil, gas and coal).

More recently the Energy Act 2004 vested rights to The Crown Estate to license the generation of renewable energy on the continental shelf within the Renewable Energy Zone out to 200nm.

The Crown Estate announced the first round of UK offshore wind farm development in December 2000 and five wind farms have been built so far. Following the success of this first round and further development of government policy, they held a tender process for a second round of larger sites in July 2003.

Round 3 was announced in 2008 with nine development zones. The successful bidders were announced in January 2010 with a potential generating capacity of 32 GW.

The Crown Estate has further awarded exclusivity agreements in Scottish Territorial Waters for 10 sites.

BVG Associates

BVG Associates is a consultancy providing expertise in the design, technology and supply chain for fuel-less renewable electricity generation systems. The team probably has the best independent knowledge of the supply chain and market for wind turbines in the UK. BVG Associates has over 75 man years experience in the wind industry, many of these being ‘hands on’ with wind turbine manufacturers, leading RD&D, purchasing and production departments. BVG Associates has consistently delivered to customers in many areas of the wind energy sector, including:

- Market leaders and new entrants in wind turbine supply and UK and EU wind farm development.
- Market leaders and new entrants in wind farm component design and supply.
- New and established players within the wind industry of all sizes, in the UK and on most continents.
- Department of Energy and Climate Change (DECC), British Wind Energy Association (BWEA), Renewables East, Scottish Enterprise, Invest NI, One North East, NaREC and other similar enabling bodies.

The views expressed in this report are those of BVG Associates. The content of this report does not necessarily reflect the views of The Crown Estate.

BVG Associates is grateful to the following companies for their help in compiling this document.

Alicat
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Hansen Transmissions
HiDef Surveying
JDR
Mainstream
Mainstream Renewable Power
McNicholas
McNulty Offshore
MPI Offshore
Noordhoek Offshore for permission to illustrate the ‘Noordhoek Pathfinder’
Oceanteam
Perry Slingsby Systems
RPS Group
RWE npower
Sea Jacks
SgurrEnergy
Siemens Plc
Siemens Wind Power
SLP Energy
SMD
Solent Composites
Subocean
Tekmar
Vestas

Contents

1. Introduction

This document is intended to be read alongside three posters illustrating the components of an offshore wind turbine; the components of an offshore substation; and the offshore processes involved in the development, installation and operation of a wind farm.

The aim is to help companies develop a greater understanding of the components and processes involved in the development of Round 3 wind farm developments, and in doing so help them realise the opportunities that will arise from the anticipated £75 billion investment over the next decade.

There is no single way to build and operate an offshore wind farm, and indeed the challenges of scale, water depth and distance from shore are such that the optimal solutions are still being developed. The pace of innovation in the wind industry has been rapid by any standards over the past decade (at the turn of the new millennium few saw the prospect of 5MW machines with rotor diameters over 120m). It is not possible to predict with any accuracy the technologies and processes that will be used during Round 3. Nevertheless, the document and posters are intended to take a forward look, assessing technological trends and extrapolating from the early Round 2 project constructions.

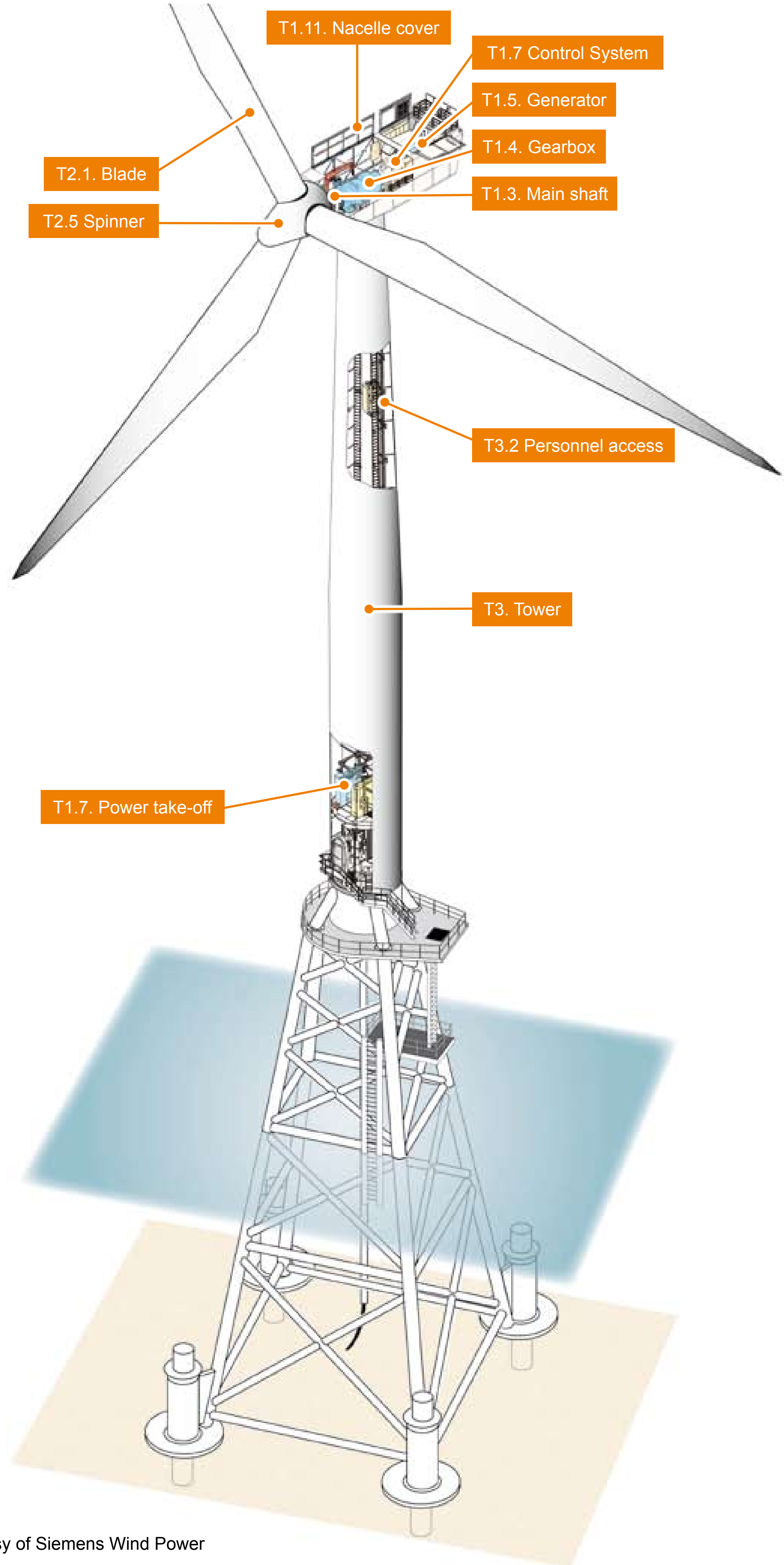
There is no typical Round 3 project. They vary considerably in their size and their distance from shore. For the purposes of this document, we have assumed that the zones will be constructed in blocks of around 500MW at around 50 miles from shore, and we will use this to inform our judgements on the cost and processes used.

The list of suppliers is indicative rather than exhaustive. We have focused on suppliers with proven capability and generally have not listed suppliers with likely future capability or located distant from the UK (for example in US or China). Nevertheless any omission does not reflect any judgement of a company's capabilities.

In all cases looking forward, there will be a need for new capacity to enter the supply chain as the industry continues to grow significantly year on year. There is also competition for some resources from the oil and gas and infrastructure sectors which has particular impact on installation vessels and export cable supply and availability of experienced staff at many levels. Further discussion of the supply chain for offshore wind is provided in Towards Round 3: Building the Offshore Wind Supply Chain published for The Crown Estate in May 2009.

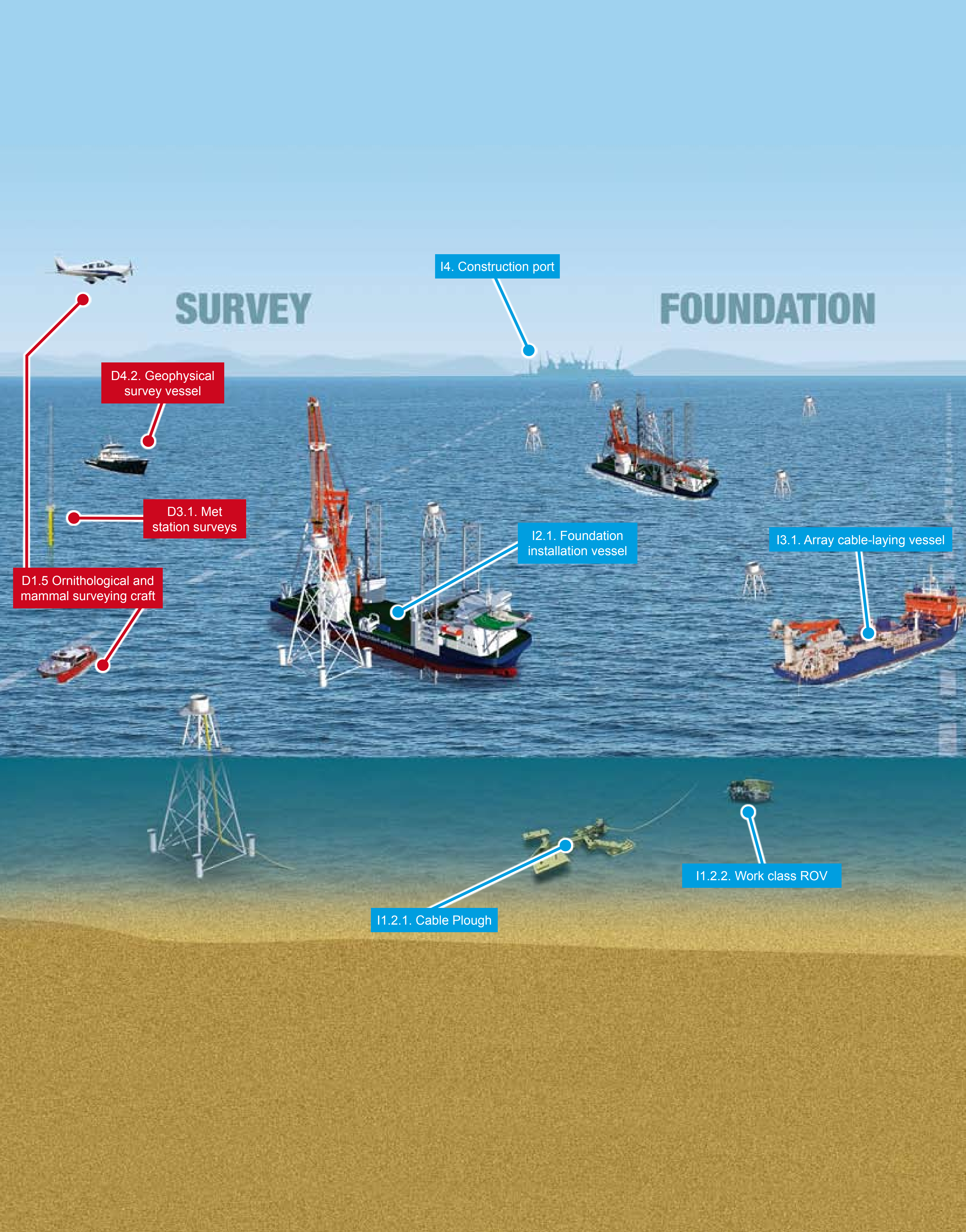
We have endeavoured to ensure that the information is as accurate and informative as possible. However, the industry is developing quickly and we at BVG Associates continue to learn. We would value feedback on the content of this document via info@bvgassociates.co.uk.

An Offshore Wind Turbine

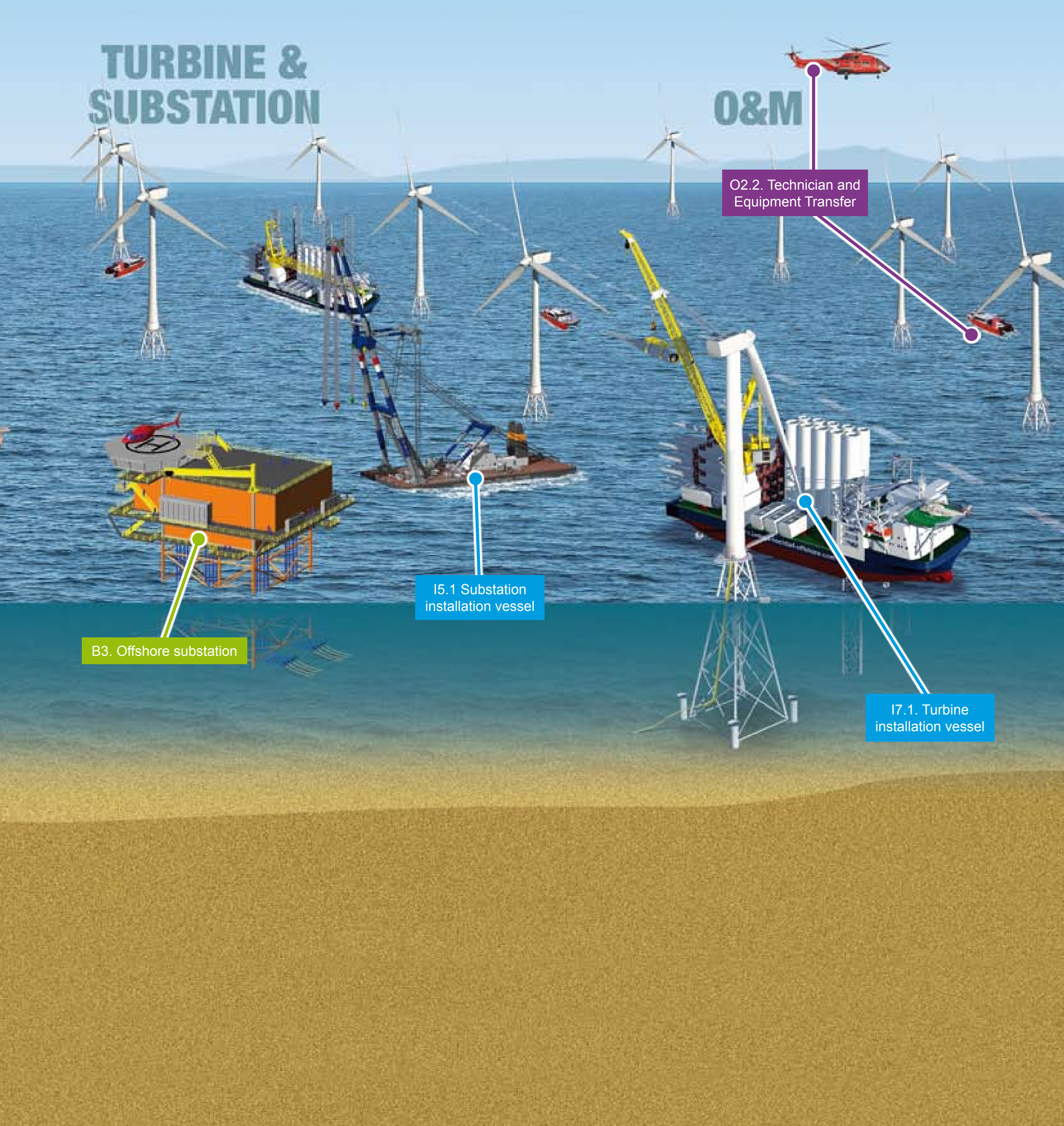


Reproduced courtesy of Siemens Wind Power

Offshore processes in the development, insta

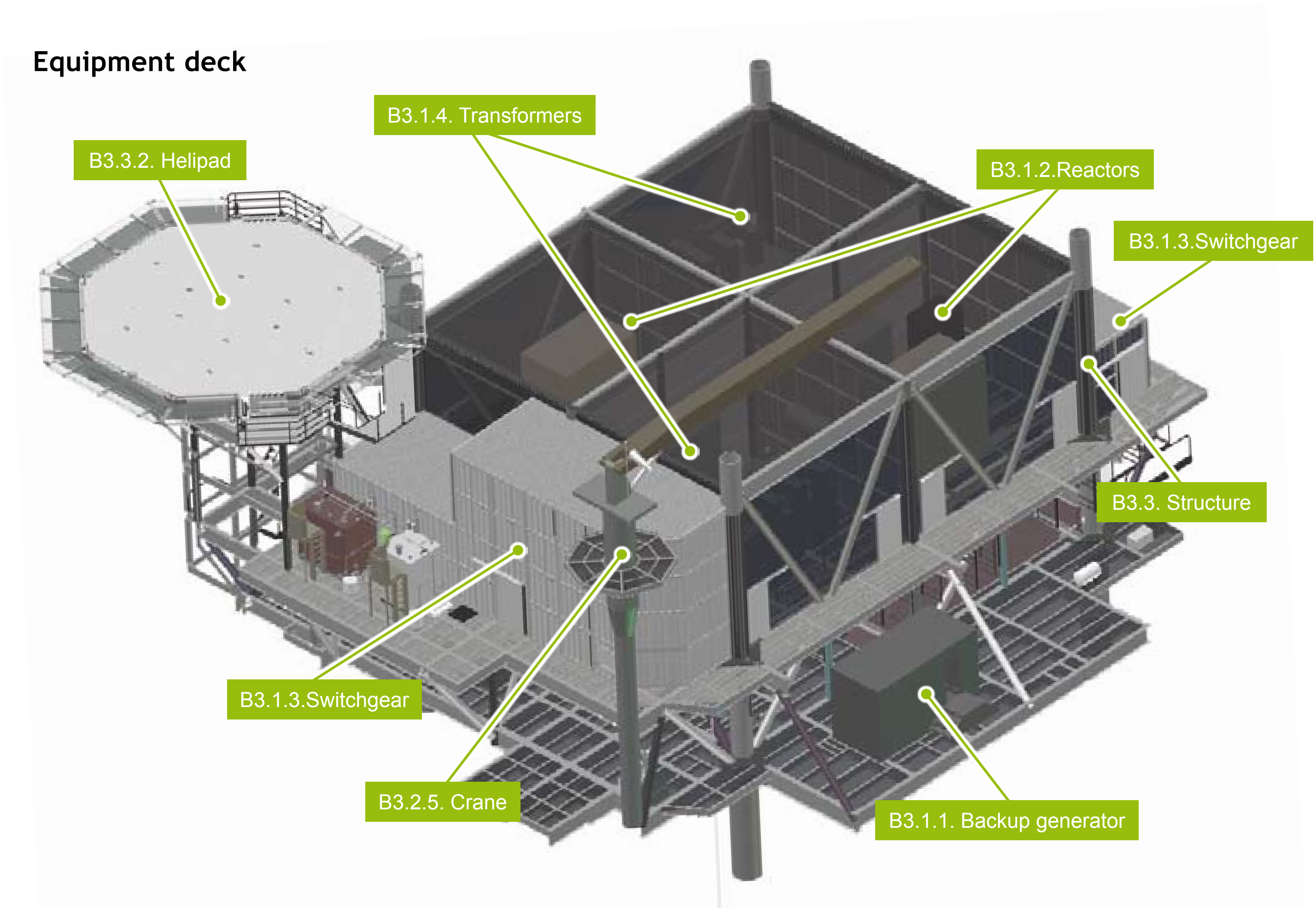


llation and operation of a Round 3 wind farm

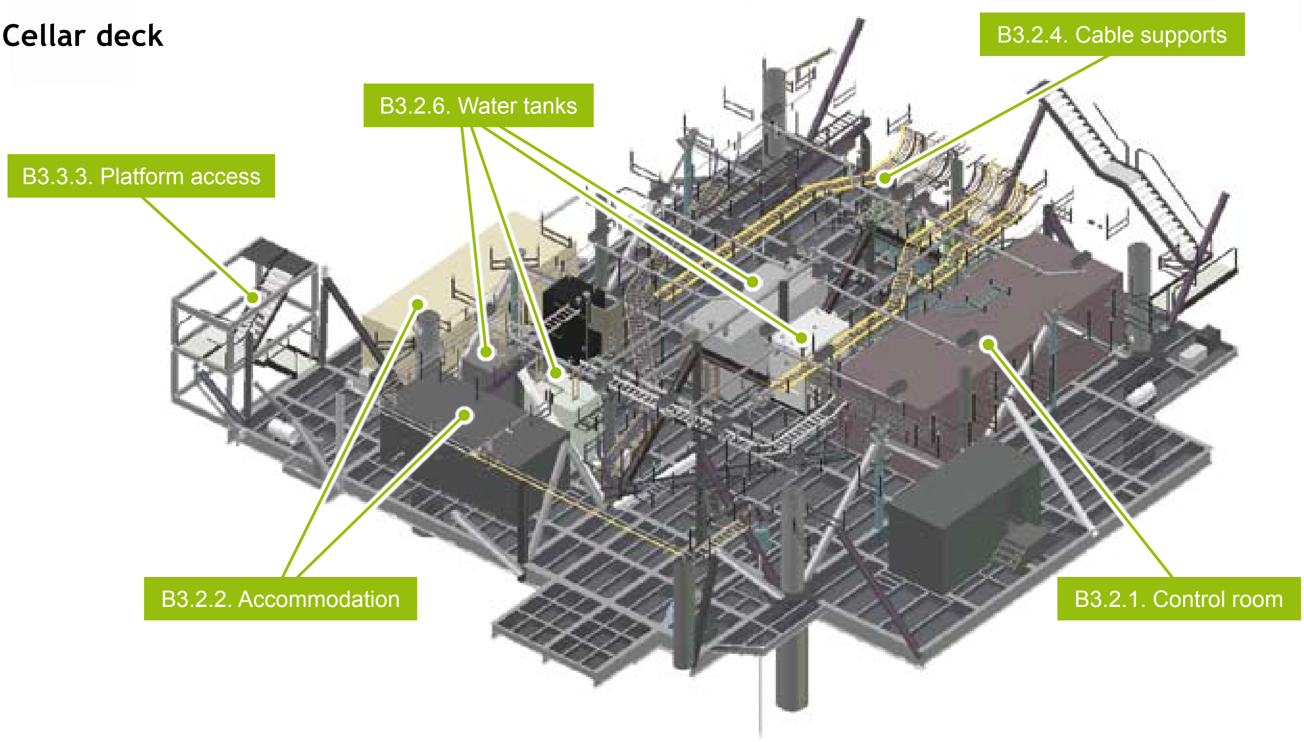


An Offshore Substation

Equipment deck



Cellar deck



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2. Development and consent

D0. Development and consent	
Function	Development and consenting covers the processes up to the point of financial close or placing firm orders to proceed with wind farm construction.
Cost	It contributes around 4% of wind farms capital costs, around £60 million for a 500 MW wind farm.
Suppliers (examples only)	The development and consenting stage is managed by the wind farm developer. UK's Round 3 is being developed by consortia of large companies, with The Crown Estate acting as a co-development partner in each Round 3 zone.
Key facts	The Department of Energy and Climate Change commissioned a strategic environmental assessment for Round 3 to inform ministerial decisions about the development of offshore wind. This helped The Crown Estate to define zones where projects have a strong chance of being granted consent and to provide significant background data to accelerate that consenting process.
Components	Development services (e.g. feasibility, licensing, planning, radar). Environmental surveys [D1]. Coastal process surveys [D2]. Met station surveys [D3]. Sea bed surveys [D4]. Front-end engineering and design [D5]. Human impact studies [D6].

D1. Environmental surveys	
Function	Environmental surveys assess any environmental impacts that a wind farm may have on species that live, use or frequent the offshore environment in the sea and in the air.
Cost	Combined environmental survey costs for a typical 500MW wind farm are in the region of £4 million.
Suppliers (examples only)	Suppliers of environmental surveys are split into those who manage the surveys and those who actually execute. Manage: AECOM, ERM, Garrad Hassan, Natural Power, Noble Denton, Mott Macdonald, PMSS, Royal Haskoning, RPS and SeaRoc. For companies who undertake specific surveys see boxes D1.1 – D1.6. Smaller, specialist companies often have the capabilities and skills to undertake specific aspects of environmental surveys and will therefore be subcontracted by others.
Key facts	Environmental surveys are one of the first tasks to be undertaken at a potential wind farm site and can take over 2 years before sufficient data is collected in order to apply for consent. Surveys require vessels and increasingly aircraft, to collect the data. Surveys look at the distribution, density, diversity and number of different species. Environmental surveys (particularly initial Regional Environmental Assessments (REAs)) are an important component of Environmental Impact Assessments (EIAs), which present the impact that the wind farm may have in the natural environment. COWRIE (Collaborative Offshore Wind farm Research Into the Environment) has been set up to advance and improve understanding and knowledge of the potential environmental impacts of offshore wind farm development in UK waters.
Components	Benthic environmental surveys [D1.1]. Pelagic environmental surveys [D1.2]. Ornithological environmental surveys [D1.3]. Sea mammal environmental surveys [D1.4]. Ornithological and mammal surveying craft [D1.5]. Onshore environmental surveys [D1.6].

D1.1. Benthic environmental surveys	
Function	Benthic studies survey species that live on the sea bed and in sediment, defining areas of similar environmental conditions on the sea bed within the proposed wind farm site.
Cost	Around £500k for a typical 500MW wind farm.
Suppliers (examples only)	ABP MER, EMU, Gardline Marine Sciences and Institute of Estuarine and Coastal Studies.
Key facts	Sampling sites are chosen so as to produce the most effective broad-scale categorisation of the overall region, as well as attempting to investigate smaller scale features such as reefs. Specific attention, for example, is given to the presence of *Sabellaria spinulosa* reefs, which indicate a particularly fragile ecosystem. Methods include "grab and collect" sampling, beam trawling, video analysis of the sea bed and acoustic data confirming the sea bed boundary. Surveys can often be done using locally based fishing vessels, onto which survey and navigation systems are installed. There is the potential for good engagement with the local fishing fraternity. These surveys are usually undertaken alongside pelagic environmental surveys [D1.2.].
Components	Laboratories are used to analyse samples of faunal life taken from the sea bed.

D1.2. Pelagic environmental surveys	
Function	Pelagic environmental surveys establish what open sea species are present within the proposed wind farm site, notably fish.
Cost	Around £500k for a typical 500MW wind farm.
Suppliers (examples only)	EMU, the Centre for Fisheries, Environment and Aquaculture Science (CEFAS) and Gardline Marine Sciences.
Key facts	Beam trawls or otter trawls (dragging a net along the sea bed) are used to sample the species present in the area. Spawning grounds for fish are a particular area of focus, and tracking local fishing vessels can aid the design of fish surveys. Surveys can often be done using locally based fishing vessels, onto which survey and navigation systems are installed. There is the potential for good engagement with the local fishing fraternity. These surveys are usually undertaken alongside benthic environmental surveys [D1.1.].

D1.3. Ornithological environmental surveys	
Function	Bird surveys establish the risks to birds that a wind farm may pose, such as changing habitat, acting as barrier to movement and mortality through collision.
Cost	Typically around £1.4 million for a 500MW wind farm. They are likely to involve both vessel-based and/or aircraft surveys. Aerial survey costs are highly dependent upon availability of suitably equipped aircraft. For ship-based surveys, typical vessel operations are in the order of £8-10k/day, plus mobilisation and transit charges, weather delays, and reporting charges.
Suppliers (examples only)	APEM, the British Trust for Ornithology, ECON, ESS Ecology, HiDef Aerial Surveying, Institute of Estuarine and Coastal Studies, RPS and Wildfowl and Wetlands Trust.
Key facts	Bird surveying is normally one of the first tasks to be undertaken at a potential wind farm site because at least 2 years is needed to get conclusive results about species population numbers and flying patterns at a site, and the results of bird surveys can have a significant effect on wind farm designs. Sea birds, resting birds and migrating birds are all surveyed to determine the use they make of the proposed area and therefore the different effects that a wind farm may have. Migrating birds are studied to assess whether the wind farm site is in a key migratory flight path. Aerial, boat-based visual surveys and radio tagging surveys are used in order to distinguish different bird species and their associated flying patterns. Flying heights are important to assess the risk of collision. Radio tagged birds are particularly useful if they come into contact with an existing wind farm, which may highlight any avoidance tactics used.
Components	Ornithological and mammal surveying craft [D1.5.].

D1.4. Sea mammal environmental surveys	
Function	Sea mammal surveys study and analyse cetaceans (whales, dolphins and porpoises) and seals to determine the effect that an offshore wind farm may have.
Cost	Around £1.4 million for a typical 500MW wind farm. Survey activity is dependent upon methodology. Sea mammal surveys can be done as part of geophysical studies, or as a separate investigation.
Suppliers (examples only)	ESS Ecology, Gardline Marine Sciences, RPS and SMRU plus small specialist ecological companies.
Key facts	Boat-based and aerial visual surveys and mammal tagging techniques are used. Marine mammal observers are used to assess the acoustic impacts during offshore activities, such as during seismic studies, in order to minimise the disturbance to cetaceans. The work requires the deployment of qualified marine biologists.
Components	Ornithological and mammal surveying craft [D1.5.].

D1.5. Ornithological and mammal surveying craft	
Function	Bird and mammal survey vessels and aircraft provide a platform for environmental surveying and observations to take place.
Cost	Typically survey vessels cost is around £10k/day for hire. Typically aircraft cost is around £1.2k for 3 hours.
Suppliers (examples only)	Vessels: Bay Marine, Gardline Marines Services, Fugro and Ocean Marine Services. Aircraft: APEM, HiDef Surveying.
Key facts	Survey vessels used for bird and mammal surveying are typically around 30m in length. Ornithological and mammal surveys are often done together to save costs. Unfavourable weather and sea conditions have to be considered in the planning of trips. Multiple crews are used, including ecologists rotating shifts of observing, recording and resting. Passive acoustic monitoring techniques and additional physical observation by qualified marine biologists are used to maximise the survey periods available. The most important specification of a survey vessel of this nature is to provide a stable platform from which surveys can be undertaken. Vessels are often high above the water level, providing a good observation level. Aircraft have a range of remote sensing instruments on board; such as high-resolution digital cameras, LiDAR, video imaging and imaging spectrometers. Twin-engine planes, with long-range fuel tanks and autopilot capabilities allow for extensive surveying offshore without the need for on-board ecologists.

D1.6. Onshore environmental surveys	
Function	Onshore environmental surveys consider the potential ecological impact that cable-laying and onshore substations may have on the onshore environment.
Cost	Around £500k for a typical 500MW wind farm.
Suppliers (examples only)	Andrew McCarthy Associates, APEM, BCM Environs, ESS Ecology, RSK Environment and Thomson Ecology.
Key facts	Wildlife surveys are often undertaken by ecological companies who have specialised capabilities for particular species. Skilled ecologists are often deployed. Studies tend to look at the distribution, density and number of different species. Wildlife ranging from badgers to small reptiles are considered, depending on the nature of the proposed site. Fragile coastal ecosystems are a prime area of focus.

D2. Coastal process surveys	
Function	Coastal process surveys examine the impact of the wind farm development on sedimentation and erosion of the coastline.
Cost	Equipped and manned survey vessels will be in the order of £4-£6k/day plus mobilisation, logistics, weather delays etc, plus final reporting charges.
Suppliers (examples only)	Specialist hydrological survey companies such as HR Wallingford, Gardline Marine Sciences and ABP MER can undertake surveys and computer and physical modelling. Survey operations using near-shore vessels are restricted to 12-hour days only, and potentially will be subject to tidal constraints.
Key facts	Coastal surveys are essential in determining land-fall sites for power cable route selections. Also of significance may be the development of ports for manufacturing, construction and operation.

D3. Met station surveys	
Function	Met stations are erected at a proposed wind farm site to monitor and analyse all aspects of meteorological and oceanographic conditions at the site.
Cost	Around £3-5 million including installation for a single met station with the cost rising the deeper and further offshore the location.
Suppliers (examples only)	Fugro-Seacore, MT Højgaard and SLP Energy.
Key facts	To date, met stations have tended to have a mast installed with a height of around 100 metres above water level (LAT) commensurate with the height of offshore turbine rotors. They are located within or up wind of the area under assessment. Near shore stations need to be protected from unauthorised access. For collection of oceanographic data only, and in time potentially a subset of other data, a lower cost solution is to install instrumented buoys.
Components	Met station structure [D3.1.]. Met station sensors [D3.2.]. Met station auxiliary systems [D3.3.].

D3.1. Met station structure	
Function	Provides the stable mounting for the sensors and auxiliary systems plus safe access for personnel.
Cost	Around £1-3 million per met station.
Suppliers (examples only)	Foundation and Platform: BiFab, Bladt, MT Højgaard, SIF-Smulder and SLP Energy. Masts: Carl C and Francis & Lewis.
Key facts	Met mast foundations are generally monopiles with transition pieces similar to turbine foundations but of much lighter construction. Jacket structures may be used for deeper water Platforms consist of a three beam structure with walkways. Far offshore these structures could also require a helipad for access and a crew refuge. Mountings for wave and current sensors extend outward from the platform. Masts are typically of galvanised steel lattice construction with a personnel climbing facility (including fall-arrest system.) A small mast (10 m) would be sufficient if platform mounted wind monitoring equipment is used such as Lidar. Personnel access to the platform is addressed in the same way as for turbines.
Components	Foundation. Platform. Mast. Personnel access facility.

D3.2. Met station sensors	
Function	Sensors provide data on meteorological and oceanographic conditions at the site of interest.
Cost	Up to of the order of £400k, depending on the scope.
Suppliers (examples only)	Meteorological sensors: FT Technologies, Gill Instruments, Kipp & Zonen, Orga Natural Power, NRG Systems, Sgurr, Thies and Vector Instruments. Metocean sensors: Nortek UK , Planet Ocean.
Key facts	Sensors are located all around the met station. Meteorological sensors include wind speed (with instruments at a number of heights or via Lidar (measuring over a range of heights with one sensor), wind direction, temperature, pressure, humidity, solar radiation and visibility. Measuring wind speeds at different heights provides critical information about the wind speed profile at the site, aiding decisions about the optimal tower height for the turbines. Metocean sensors include wave, sea level and current sensors (eg. acoustic Doppler current profiler), sometimes sea bed-positioned. Multiple sensors are used to avoid periods of lost data. Bird radar and hydrophones detecting cetacean activity can provide additional information to vessel and air-based environmental surveys.

D3.3. Met station auxiliary systems	
Function	Auxiliary systems include power supplies, navigational aids and logging and telemetry systems.
Cost	Of the order of £100k.
Suppliers (examples only)	Navigational aids: Obelux, Orga and Tideland. Logging and telemetry: Fugro Geos, PowerPoint Technical Services, VHF Teknik and XL Systems.
Key facts	Off-grid power supplies generally incorporate solar panels and small wind turbines plus batteries for energy storage. Navigation aids may include hazard lighting, fog horn, AIS and illuminated identification number panel for shipping. Loggers store and process all data recorded in parallel to transmission to shore. Telemetry facilitates real-time transmission of information by radio GSM or satellite.

D4. Sea bed surveys	
Function	Sea bed surveys analyse the sea floor of the proposed wind farm site to assess its conditions and characteristics.
Cost	Around £9 million for a 500MW wind farm.
Suppliers (examples only)	Suppliers include EMU, Fugro, Gardline Marine Sciences, GEMS, RPS, Ramboll.
Key facts	Sea bed surveys consist of two main parts; Geophysical surveys of sea bed features and bathymetry Geotechnical surveys of the sea bed characteristics. Sea bed surveys are an important component of the development process and aid a number of processes, such as choosing the foundation design and the wind farm layout, as well as minimising risk during installation activities. Specialised vessels are deployed to undertake the surveys.
Components	Geophysical surveys [D4.1]. Geophysical survey vessels [D4.2]. Geotechnical surveys [D4.3]. Geotechnical survey vessels [D4.4].

D4.1. Geophysical surveys	
Function	Geophysical surveys establish sea floor bathymetry, sea bed features, water depth and stratigraphy, as well as identifying hazardous areas on the seafloor.
Cost	Approximately £1.5 million for a 500MW wind farm.
Suppliers (examples only)	ABP MER, EMU, Fugro, Gardline Marine Sciences, GEMS, Ramboll, Wessex Archaeology and Titan Environmental Surveys.
Key facts	The techniques used consist of bathymetry mapping with conventional single or multi-beam echo soundings or swathe bathymetry, sea floor mapping with side scan sonar or magnetometer readings, acoustic seismic profiling methods and high resolution digital surveys using airguns. Surveys run along transects across zones within the proposed wind farm site. 'Snap shot' data is used to monitor the extent of movement in sea bed sediments. Information from geophysical surveys is used to aid the design and implementation of benthic and geotechnical surveys, so they are therefore undertaken near the beginning of the development process. Data from geophysical surveys are used to produce charts and maps for GIS systems, which are then used for site layout design. Geophysical surveys can be used to identify unexploded ordnance on the seafloor. Geophysical surveys may also consider marine archaeology that may be present in the wind farm site. This is typically dealt with by specialist archaeological survey companies, and is offered as a service in conjunction with the geophysical surveys.

D4.2. Geophysical survey vessels	
Function	Specialist vessels are used to carry out geophysical surveys of the sea bed.
Cost	Dependent upon survey activities required but for Round 3 sites, a fully mobilised offshore vessel working 24 hour days is considered essential. Fully equipped and manned vessels will be approximately £14-16k/day, plus mobilisation and demobilisation charges, weather or transit (at standby rates), plus reporting charges.
Suppliers (examples only)	EMU, Gardline Marine Sciences, GEMS and Fugro.
Key facts	Geophysical vessels are typically around 50m in length. The vessels must provide a stable platform even in unfavourable sea and weather conditions. Multiple crews, including highly specialised equipment operators, are utilised and the vessel has sleeping berths and living quarters to allow the vessel to have an operational endurance of up to a month. Crew rotations month by month enable a constant flow of data observation, processing and interpreting.

D4.3. Geotechnical surveys	
Function	Geotechnical site investigations are conducted following the geophysical survey to use the information obtained to target soil strata changes or specific sea floor features.
Cost	Approximately £7.5 million for a 500MW wind farm.
Suppliers (examples only)	Suppliers include Fugro Seacore, Gardline Marine Sciences and GEMS.
Key facts	Geotechnical surveying requires specialised equipment and skilled personnel. The scope of the investigation depends on the type of foundation being considered and the variability in the sea bed characteristics. A number of boreholes (to depths in the order of 50-70m) and cone penetration tests are carried out to investigate the physical characteristics of the sea bed. Offshore laboratories are often used to investigate samples taken. Resultant data from the geotechnical surveys are combined with results of the geophysical survey, to improve the geological model prior to the design and installation of foundations.

D4.4. Geotechnical survey vessels	
Function	Specialist vessels carry out geotechnical surveys of the sea bed.
Cost	Day rates are in the order of £40k to £70k, plus mobilisation, transit & weather delays (at standby rates) plus laboratory analyses and reporting charges. Total cost is likely to be of the order of £5 million for a typical 500MW wind farm.
Suppliers (examples only)	Suppliers include Fugro, Gardline Marine Sciences and GEMS.
Key facts	Geotechnical survey vessels are over 90m long. The vessels have to be large in order to carry large equipment on board, such as drilling rigs and cranes, and to be able to operate independently in remote locations. Jack-up vessels can be used (albeit smaller than those used for foundation and turbine installation). The vessels must be able to position themselves at specific locations for borehole sampling and must be able to withstand unfavourable sea and weather conditions. The vessels must act as a stable platform for the acquisition of samples. Due to the expense of hiring these vessels, multiple crews, including highly specialised equipment operators, are utilised and the vessels have sleeping berths and living quarters to allow the vessel to have an operational endurance of over a month. Offshore laboratories also allow for data acquisition and processing onboard. Crew rotations month by month enable a constant flow of data collection, processing and interpreting.

D5. Front end engineering and design studies	
Function	Front end engineering and design (FEED) studies address areas of technical uncertainty and develop the concept of the wind farm in advance of contracting.
Cost	Of the order of £1 million for a 500MW wind farm.
Suppliers (examples only)	Garrad Hassan, KBR, Noble Denton, ODE, Ramboll, RES and Sgurr Energy.
Key facts	Key parameters such as turbine size, foundation type, wind farm layout and grid connection method are considered to optimise economic viability. Also included is planning of onshore and offshore operations and determining contracting methodologies and the development of key risk management and health and safety policies. Output of studies is used by construction management teams in order to implement the wind farm.
Components	Specialist subcontracts may be placed for specific activities including preliminary foundation design.

D6. Human impact studies	
Function	This is an assessment of the impact that a proposed wind farm may have on the community living in and around the coastal area near the wind farm. This includes visual and noise assessment of the proposed wind farm and the socio-economic impact that coastal infrastructure, such as ports, will have.
Cost	£100k
Suppliers (examples only)	Ecogen, Entec, Garrad Hassan, Pegasus Planning Group, RPS and SgurrEnergy.
Key facts	Visual assessments comprise of photomontages from specific viewpoints of what the proposed wind farm will look like. Noise assessments assess that potential noise impacts and determine whether the impact of the proposed wind farm is within the guidance of ETSU R97 standard. The socio-economic study accesses the impacts of a wind farm or coastal infrastructure, e.g. a port, such as changes in employment, transportation or recreation, or changes in the aesthetic value of a landscape. It estimates the impacts on the local society, not only of these socio-economic changes, but also of the composite of biological, geological, and physical (biogeophysical) effects caused by the proposed change on the local area. Socio-economic studies include a mix of objective and subjective data. Objective data can include statistics on age, sex, and income distributions, ethnic origin, mortality, housing type and occupancy, and education. Subjective data can be derived from surveys and observations. These are used to provide systematic estimates of the ways in which various groups perceive their socio-economic environment and thus the impact of the proposed change. Studies consider the onshore cable route and substation. Studies on human impacts usually form part of an Environmental Impact Assessment (EIA).

3. Wind turbine

T0. Wind turbine	
Function	The turbine converts kinetic energy from wind into three phase AC electrical energy.
Cost	Around £6 million for a 5MW turbine.
Suppliers (examples only)	Wind turbine manufacturers. The two that have dominated the market to date are Siemens and Vestas (both with Danish headquarters). Others with commercial-scale turbines installed offshore are REpower and Areva-Multibrid (both with German headquarters). Most of the other top-10 manufacturers of large onshore wind turbines are developing products for the offshore wind market, including European, Chinese and US companies. A number of new players are developing innovative turbines specifically for offshore wind.
Key facts	Early offshore wind farms used turbines adapted from the onshore market. Increasingly, turbines are being designed specifically for offshore deployment with larger capacities (i.e 5MW+, rather than up to around 3MW for onshore use). There is plenty of room for innovation in design, where there is increased focus on reliability and maintainability and decreased impact of noise, visual and transport constraints. As of end 2009, none of these wind turbine manufacturers have significant manufacturing facilities in the UK, but a number are considering significant inward investment.
Components	Nacelle [T1.]. Rotor [T2.]. Tower [T3.].

T1. Nacelle		
Function	The nacelle supports the rotor [T2.] and converts the rotational energy from the rotor into three phase AC electrical energy.	
Cost	Around £2.5 million per turbine for a large 5MW offshore turbine.	
Suppliers (examples only)	Nacelles are assembled by the wind turbine manufacturer, using components generally sourced from a range of external suppliers.	
Key facts	Typical dimensions are 10-15m x 4m x 4m, with mass 150-300 tonnes. It takes 10-20 man-days to assemble a large nacelle and there is a preference to assembly close to supply chain, rather than close to market. Establishing local assembly of nacelles in a given market opens up possibilities for significant local supply. Before dispatch, the nacelle undergoes a functional test before being prepared for transport and storage.	
Components	Nacelle bedplate [T1.1.]. Main bearing [T1.2.]. Main shaft [T1.3.]. Gearbox [T1.4.]. Generator [T1.5.]. Power take-off [T1.6.]. Control system [T1.7.].	Yaw system [T1.8.]. Yaw bearing [T1.9.]. Nacelle auxiliary systems [T1.10.]. Nacelle cover [T1.11.]. Small engineering components [T1.12.]. Fasteners [T1.13.]. Condition monitoring system [T1.14.].

T1.1. Nacelle bedplate	
Function	The bedplate supports the drive train and the rest of the nacelle components and transfers loads from the rotor to the tower.
Cost	The bedplate for a conventionally arranged 5MW turbine costs of the order of £100-£120k.
Suppliers (examples only)	Bedplates are either cast SG iron or steel fabrications. Casting: Eisengiesserei Torgelow, Felguera Melt, Fonderia Vigevanese, Gusstec, Metso, MeuselWitz, Rolls Royce, Sakana, Siempelkamp and Vestas. Only some of these can manufacture the largest bedplates for offshore turbines today. Fabrications: A reasonable range of steel fabricators exist capable of manufacture of bedplates.
Key facts	Frequently, bedplates are manufactured in two parts. The heavier section supports the gearbox [T1.4.] and transfers loads from the rotor to the tower [T3.] and is frequently cast. A lighter section supports the generator [T1.5.] and other components at the rear of the nacelle and is normally fabricated. The heavier section generally also supports the yaw system [T1.8]. The structures are designed by the wind turbine manufacturer and generally manufactured by sub-suppliers. Design considerations include fatigue and extreme loads, stiffness and assembly, and maintainability features such as accessways to critical components. Once manufactured, the items are machined, shotblasted, metal sprayed and epoxy painted before delivery to the wind turbine manufacturer. For a 5MW turbine with conventional layout, the bedplate has total mass of the order of 80 tonnes and is of the order of 4m x 3m x 10m. Material is typically EN-GJS-400-18U-LT grade SG iron or a standard 355-grade steel
Components	Large SG iron or fabricated steel structure. Machining and painting.

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T1.2. Main bearing	
Function	The main bearing supports the rotor and transfers some of the rotor loading to the nacelle bedplate [T1.1.].
Cost	The main bearing arrangement (including housing) for a large 5MW turbine costs of the order of £60-80k.
Suppliers (examples only)	FAG (Schaeffler), Kaydon, Liebherr, Rollix, Rothe Erde and SKF.
Key facts	A number of different bearing arrangements exist. A common, relatively conservative approach for offshore turbines is to support the main shaft [T1.3.] with a bearing at each end (eg. for Siemens 3.6MW and Repower 5 and 6MW turbines). Such arrangements may use a combination of spherical roller bearings (to provide axial location) and a self-aligning roller bearing. Bearings are often heated prior to mounting on the main shaft in order to provide a robust, stress-concentration free connection. Cast-iron bearing housings provide stiff supports for these bearings and connection to the nacelle bedplate. For a 5MW turbine, a pair of main shaft bearings and housings may have mass up to of the order of 25 tonnes.
Components	Forged rolled ring, machined and hardened. Rolling elements (spherical, crowned cylindrical / tapered). Rolling element support (cage). Lubricants and seals. SG iron bearing housing.

T1.3. Main shaft	
Function	The main shaft transfers torque from the rotor to the gearbox. It is supported at the rotor end by the main shaft bearing and at the other end either by the gearbox or separately mounted bearing.
Cost	A main shaft for a 5MW turbine costs of the order of £100k.
Suppliers (examples only)	Brück, Euskal, Skoda and Thyssen.
Key facts	Conventionally, the rotor is flange-connected to the main shaft using a single or double row of fasteners [T1.13]. The main shaft normally also has a ring of holes for use in positively locking the rotor in fixed position for maintenance activities. It normally has a central bore through which control signals, control power supplies and electrical or hydraulic power are passed to the hub for operation of the blade pitch system. For a large 5MW turbine, the main shaft may have a mass of up to the order of 30 tonnes and be forged and machined from a high grade steel such as 42CrMo4 or cast hollow from EN-GJS-400-18U-LT. Even for such a large item, fatigue loading is important as the rotating shaft is supporting the mass of the rotor as well as the aerodynamic torque and thrust loads. It is critical to minimise stress concentrations.
Components	Forged shaft. Machining, NDT and painting.

T1.4. Gearbox	
Function	The gearbox converts rotor torque at a speed of 5-15 rpm to a speed of up to around 1500rpm for efficient conversion to electrical energy by the generator.
Cost	A 5MW gearbox costs £700k to £1m.
Suppliers (examples only)	Bosch Rexroth, Eickhoff, Hansen, Moventas, Renk and Winergy.
Key facts	The gearbox is a critical item in the wind turbine drive train, with much attention given to the long-term operation given a history of variable quality and reliability. Typically designs incorporate a planetary first stage followed by two higher-speed parallel (helical) stages. Normally, a brake disk is mounted at the rear (high-speed) end. Design drivers include peak torques coming from a range of loadcases; also loads in storms and during braking or other abnormal events. Careful consideration is given to the variation in bearing and gear contact points due to a wide variation in operating power levels during turbine life, including periods of standstill and operation under minimal loading, introducing the possibility of skidding within bearings. Design methodologies couple empirical rules of thumb, detailed dynamic analysis and workshop testing. Automatic heating is frequently applied before restart in cold conditions and cooling is designed typically to keep operating temperatures below 70˚C. Cooling of the generator may be combined. Lubricants specific to wind turbine gearboxes have been developed, also now with consideration to environmental impact. Typically, the gearbox has a bore (say 100mm) in the central shaft (along the axis of the main shaft) to facilitate provision of control signals, control power supplies and electrical or hydraulic power to the hub for operation of the blade pitch system. Total gearbox mass for a 5MW turbine may be up to 65 tonnes, with individual internal components sized to facilitate in-situ repair using on-board cranes. In some designs, gearboxes and high-speed generators are being replaced by low-speed, direct-drive generators. Although historically they are heavier and more expensive, such designs are developing rapidly and may in time prove to be more reliable.
Components	SG iron castings (including higher grade, say EN-CJS-700-2U) for items such as planned carrier) and steel forgings. Cylindrical, taper and spherical roller bearings; also plain bearings. Gears.

T1.5. Generator	
Function	The generator converts mechanical energy to electrical energy.
Cost	Depending on generator type, a 5MW generator costs of the order of £200-£250k.
Suppliers (examples only)	Suppliers include ABB, Elin, Ingeteam, Leroy Somer, VEM and Winergy.
Key facts	For the last 10 years, most wind turbines have used doubly-fed induction generators (DFIGs), with high-speed electrical slip rings transferring part of the output power from the rotor. Others use wound or permanent magnet synchronous machines. Almost all operate at variable speed, with grid connection via an AC-DC-AC converter. This enables the smoothing of drive train loading and the optimisation of aerodynamic performance without the need for a variable ratio gearbox. Efficiency is critical, especially at part load, as on average a wind turbine spends significant hours generating 20% to 80% of rated power in low-to-medium wind speeds. Water cooling is common in order to maximise efficiency and compactness whilst limiting noise levels. The generator for a 5MW turbine may have mass up to 20 tonnes. Generator bearings are designed to avoid passage of electrical current and with special emphasis on lubrication. Typically, these are specialist deep-groove bearings, sometimes with ceramic rolling elements. Related, but not part of the scope of supply of the generator, is the coupling that connects the generator to the gearbox. As both components are flexibly mounted and the wind turbine structure is relatively flexible compared to the loading applied, such couplings generally have significant misalignment capability.
Components	Castings. Windings. Bearings. Sensors. Slip rings for DFIG generators. High-speed shaft coupling.

T1.6. Power take-off	
Function	Receives electrical energy from the generator and adjusts voltage and frequency for onward transfer to the wind farm distribution system.
Cost	The components listed together cost of the order of £400k.
Suppliers (examples only)	Power converters: ABB, AMSC, Converteam, IDS, Ingeteam, The Switch, SEG and Winergy. Transformers: ABB, GE, CG (Pauwels), Schneider, Siemens and SGB. Switchgear: Areva T&D, CG (Pauwels), S&C and Siemens. Cabling: Draka, Nexans and Prysmian.
Key facts	For some time, most wind turbines have run with variable speed generators connected to the grid via an AC-DC-AC power converter. There is a range of different generator/converter architectures used. With high power density, today's IGBT-based power converters frequently are water cooled. Critical to consider in the design of power converters are requirements imposed by grid operators for wind turbines to support and stabilise the grid during grid faults and to provide or consume reactive power on demand. Transformers are sometimes placed in the nacelle [T1.]; sometimes at the base of the tower [T3.]. Typically they transform sub-kV to 33kV for distribution around the wind farm array and are of dry (cast resin) design, meeting detailed corrosion, environmental and combustion requirements. Typically they are forced-air cooled. Switchgear is now being designed specifically for wind turbine applications, for example gas-insulated for compactness and safety at up to wind farm distribution voltage. For cables, one difference from conventional industrial applications is that down-tower cabling is routed to enable the cables to twist, allowing the nacelle two complete revolutions of movement by the yaw system [T1.8] before an untwisting operation is required.
Components	Power converter. Transformer. Switchgear. Cables.

T1.7. Control system	
Function	Provides supervisory control (including health monitoring) and active power and load control in order to optimise wind turbine life and revenue generation, whilst meeting externally imposed requirements.
Cost	The control system for a 5MW turbine costs of the order of £70k.
Suppliers (examples only)	Bachmann, DEIF, Garrad Hassan, KK-Electronic and Mita Teknik.
Key facts	Control system software is usually developed in-house by wind turbine manufacturers in order to take into account the dynamics of the mechanical and electrical parts of the turbine. Each wind turbine can operate independently from external intervention, starting and stopping in response to changing wind conditions. The control system carries out regular health checking using of the order of 100 sensors monitoring key components and sub systems. In response to unexpected data, it takes decisions to curtail operation and provides regular reporting to the Supervisory Control and Data Acquisition (SCADA) system. The control system also takes control input from the SCADA system, for example to derate wind turbines in response to utility customer requests. Key control parameters for active power and load control are rotor speed, output power and the pitch angle of each blade. Control intelligence may be distributed around the turbine, including in the hub. Control panels contain controller PLCs plus standard panel hardware to interface with sensors and auxiliary systems and combined may weigh up to 500kg. In some cases, CANbus or similar systems are used for interfacing between controller hardware and sensors, including via fibre-optic cables. In parallel to the control system, a safety system protects the turbine from control system or operator error. Key sensors for this overriding safety system include speed and vibration sensors. Lastly, an emergency system with physical press-button and/or chord inputs is put in place to bring the rotor to a halt in the event of risk to maintenance personnel.
Components	Control panels. Control system hardware and software. Sensors. Safety and emergency systems.

T1.8. Yaw system	
Function	The yaw system orients the nacelle to the wind direction during operation.
Cost	The yaw system for a 5MW turbine costs of the order of £100k.
Suppliers (examples only)	ABB, Bonfiglioli, Bosch Rexroth and VEM.
Key facts	The yaw system for a large offshore turbine typically consists of 6-8 geared electric motors mounted on the nacelle bedplate [T1.1.], acting on the toothed inner ring of the yaw bearing [T1.9.]. Each drive has mass up to 1 tonne and typically has ratio 200-300:1. To avoid constant varying loading on the drives, a series of around 10 calliper brakes (each of mass approx. 150kg) are hydraulically applied to hold the yaw bearing in position, except when movement is required. Even during movement (which may be the order of a few degrees every few minutes in order to align the nacelle to the wind direction), the yaw brakes act to damp movement. Sensors measure the position of the nacelle and limit switches prevent over-twisting of the cables down the tower. Some wind turbines use hydraulically operated yaw motors, providing compliance to relieve tower top loading.
Components	Yaw motors and associated gearboxes. Yaw brakes. Sensors.

T1.9. Yaw bearing	
Function	The yaw bearing connects the nacelle and tower, enabling the yaw system to orient the nacelle to the wind direction during operation.
Cost	A yaw bearing for a 5MW turbine costs of the order of £40-£50k.
Suppliers (examples only)	IMO, Liebherr, Rollix and Rothe Erde.
Key facts	Bearings are typically single-row 4-point contact ball bearings made from forged rings of up to 5-5.5m diameter for a 5MW turbine, typically of a 42CrMo4 steel, quenched and tempered. Balls are typically material 100Cr6. Total bearing mass may be up to 6 tonnes. Raceways are hard-turned or ground after induction hardening. Bearings see a complex load pattern and operate with long periods of no or only occasional movement over a small proportion of a revolution. Critical to long-term performance is the provision of flat mounting services (ie. tower flange machined after welding). Bearings incorporate gear teeth to mesh with the yaw drives. Bearings are typically metal sprayed and/or painted. In general, yaw bearings have fewer operational issues than blade bearings [T2.3.]. Some wind turbine manufacturers use plain bearings, incorporating low-friction pads rather than rolling elements.
Components	Forged rings, machined, hardened and surface finished. Balls. Seals. Grease.

T1.10. Nacelle auxiliary systems	
Function	A number of auxiliary systems facilitate ongoing unattended operation of the wind turbine for the vast majority of the time, and support planned intervention, which typically should be only on an annual basis.
Cost	Combined costs of all auxiliary systems are of the order of a few percent of large component costs.
Suppliers (examples only)	Brake: Siegerland, Stromag and Svendborg. Cooling: Hydac, Windsyn. Air conditioning: Cotes. Anemometry: Climatronics, Gill Instruments, FT Technologies, NRG Systems and Vector Instruments. Fire protection: Danfoss, Firetrace and Minimax. UPS: AKI Power Systems. Internal service crane: Effer, Hiab, Liftra, Palginger Marine
Key facts	Typically a mechanical brake is mounted at the rear of the gearbox [T1.4.]. Primary braking of the wind turbine in the event of an emergency is achieved by pitching the blades. In some cases also electrodynamic braking is used but a mechanical brake is also present, frequently with a hydraulically applied calliper acting on a risk of the order of 700mm diameter. A rotor lock enables locking of the rotor in a fixed position for maintenance activities. Typically for large turbines it consists of a peg-and-hole arrangement with manual or automatic hydraulic actuation engaging one or more pegs with holes on the front flange of the main shaft [T1.3.]. A large offshore turbine is around 92-94% efficient in converting kinetic energy in the rotor to electrical energy, requiring at times up to 300kW of heat to be dissipated from gearbox, generator and electrical system. In order to protect all nacelle components from corrosion, typically the nacelle is well sealed and the whole area is served by a local air conditioning system. Mounted on the roof of the nacelle is an anemometry mast with sensors measuring wind speed and direction. Frequently, these functions are combined into sonic devices, rather than using traditional cup anemometers and wind vanes. Frequently, fire protection systems are provided in order to sense and suppress fire in different areas of the turbine. Within electrical panels, nitrogen is used. In open spaces such as the nacelle, fine water spray systems are employed. The fire protection systems have separate control and condition monitoring from the turbine controllers. Typically, in order to facilitate orderly shutdown of the turbine under grid loss conditions, UPS systems are used to power the control, safety and emergency systems and provide emergency lighting in the tower to facilitate safe exit of personnel. In some cases, UPS power is required in order to ensure requirements for rotor warning lights on the tips of blades continue to operate for an agreed period. The internal service crane for a large turbine is designed to lift key turbine components during maintenance activities, typically up to 6 tonnes. The crane is controlled wirelessly and operates through cut-outs in the nacelle cover to lower components to the access platform.
Components	Brake. Rotor lock. Cooling. Anemometry. Fire protection. UPS. Internal service crane.

T1.11. Nacelle cover	
Function	The nacelle cover provides weatherproof protection to the nacelle components plus support and access to external components such as coolers, wind measurement equipment and lighting protection devices.
Cost	For a standard 5MW turbine, the nacelle cover costs of the order of £60-90k.
Suppliers (examples only)	Bach Composites Industry and Eikboom supply glass fibre nacelle covers.
Key facts	As well as providing environmental protection, frequently it supports lighting and other auxiliary supplies and acts as a faraday cage to protect nacelle components from lightning damage. It is fitted during assembly of the nacelle, either before or after final test, and plays a valuable role in protecting nacelle components during transport to the wind farm site. It is designed to withstand wind loading and provide access to lifting points on the nacelle bedplate [T1.1.] for transport and installation. Careful design also facilitates exchange of nacelle components through hatches or hinged openings in the roof, side or floor. The nacelle cover is typically manufactured in a number of sections from glass fibre or steel and may have mass up to 20 tonnes.
Components	Fibreglass or steel construction. Built-in or post-assembled auxiliary systems (eg. lighting). Maintenance support features.

T1.12. Small engineering components	
Function	A range of frequently standard engineering components make up the rest of the nacelle assembly.
Cost	Costs generally are low.
Suppliers (examples only)	Many items are off-the-shelf or can be manufactured by a range of metalworking companies.
Key facts	Anti-vibration mounts support the generator [T1.5.] and sometimes other critical components.
Components	Guards, flooring, drip trays and other fixed maintenance aids. Anti-vibration mounts. Lighting. Small fasteners and other accessories and consumables used during nacelle assembly.

T1.13. Fasteners	
Function	Fasteners (either bolts or studs) are used in a range of critical bolted joints, for example connecting rotor to main shaft, main bearing housings to nacelle bedplate and yaw bearing to the underside of nacelle bedplate.
Cost	£10-15k is spent per turbine on large fasteners.
Suppliers (examples only)	August Friedberg, Cooper & Turner, Fuchs & Sanders, Gexpro Services and Wind-Fix.
Key facts	Fasteners for critical structural joints within large turbines are typically of size M30 or M36 and grade 10.9. Often, the fasteners are specified to have threads rolled after heat treatment to improve fatigue properties. Coatings provide corrosion protection and repeatable torque characteristics are standard. All critical fasteners are preloaded either using hydraulic torque tooling or (in the case of studs) hydraulic tensioning.

T1.14. Condition monitoring system	
Function	Many wind turbine manufacturers offer add-on condition monitoring systems to provide additional health checking and failure prediction capability.
Cost	Systems cost of the order of £10-20k depending on complexity.
Suppliers (examples only)	Wind turbine manufacturers, Brüel & Kjær Vibro, Gram & Juhl, SKF, SecondWind
Key facts	Many of today's condition monitoring systems frequently make decisions about individual components (such as the gearbox) via sensors measuring parameters for that component only. This situation is changing, with latest systems considering a range of sensors and controller outputs in order to make holistic decisions about all drive train components. Condition monitoring systems on the rotor [T2.] are able to assess control behaviour as well as blade health. In some cases, systems send data to a central data store in order to facilitate analysis over a large number of turbines.
Components	Sensors. Condition monitoring hardware and software. Remote communication interface.

T2. Rotor	
Function	The rotor extracts kinetic energy from the air and converts this into wind into rotational energy in the drive train.
Cost	The rotor for a 5MW turbine costs of the order of £1.2-£1.5 million.
Suppliers (examples only)	Wind turbine rotors are always designed and supplied by the wind turbine manufacturer as part of the complete wind turbine.
Key facts	The current generation of horizontal axis turbines have three blades, but designs with two blades are being developed which may be better suited to offshore use. The blades [T2.1.] are connected to the turbine drive train via a central hub. In all offshore wind turbines, the blades are mounted on bearings [T2.3.] to allow adjustment of the pitch angle. Fasteners are used to connect the blades to blade bearings and blade bearings to hub. These are typically M30 or M36 grade 10.9 bolts or studs (see T1.13). A typical rotor for a 5MW turbine has mass 90-150 tonnes. A typical rotor diameter is 120-140m. There are no fundamental limits to the size of rotors for offshore turbines, though for the same design, mass increases faster than the additional energy generated.
Components	Blades [T2.1.]. Hub casting [T2.2.]. Blade bearings [T2.3.]. Pitch system [T2.4.]. Spinner [T2.5.]. Rotor auxiliary systems [T2.6.]. Fabricated steel components [T2.7.]. Fasteners [T1.13.].

T2.1. Blades	
Function	The blades capture the energy in the wind and transfer torque and other unwanted loads to the drive train and rest of the turbine.
Cost	A blade for a 5MW turbine costs of the order of £250-350k.
Suppliers (examples only)	Around two thirds of blades are manufactured in-house by the wind turbine manufacturer, including most offshore blades. LM Glassfiber is the leading independent supplier, with coastal facilities in Poland.
Key facts	Blades are typically made from fibreglass and epoxy resin, although there are variations between designs, with some using carbon fibre; others use polyester resins. With both cyclically varying aerodynamic and reversing gravity loading, both fatigue and extreme loading inform the design in different regions of the blade. Extreme loads may come from storm loading, specific events such as shutdowns due to control system failure, or from the high number of hours of operating in a turbulent wind field. Natural frequency is another critical design consideration, against a range of driving frequencies due to the rotor rotation, as is deflection stiffness, where avoidance of tower strike is critical. Blades for a 5MW turbine are generally over 60m long and over 5m wide at their broadest point, with mass 15-25 tonnes. The blade root [T2.1.2.] provides a critical connection to the blade bearing [T2.3.]. A lightning protection system [T2.1.3.] is designed into the blade, including connection to enable lighting to pass safely to the nacelle and tower. In some applications, aviation lights mounted on the tips of blades are required. These may illuminate only when the blade is oriented vertically upwards.
Components	Structural composite materials [T2.1.1.]. Blade root [T2.1.2.]. Lightning protection [T2.1.3.]. Aviation lights.

T2.1.1. Structural composite materials	
Function	Composite materials are used to provide an efficient, strong and relatively light blade structure.
Cost	Materials make up of the order of half the finished cost of a blade.
Suppliers (examples only)	Airtech, Alcan, Diab, Gurit, Hexel, Owens Corning, PPG, SGL and Zoltek.
Key facts	The typical manufacturing process for a blade is to make two full-length shells using a resin infusion process and consumable vacuum bags. These shells are either glued around a central load-bearing spar or structural elements are incorporated into the blade shells and a strong load-bearing connection between them is provided using glass fibre shear webs. Compromises are made between optimum aerodynamic shape (generally low thickness) and optimum structural shape (higher thickness). Key parameters that define blade shape along the blade are chord (length of aerofoil cross-section), thickness of aerofoil cross section, twist (angular rotation of aerofoil) aerofoil shape and position of aerodynamic centre. These parameters are optimised during blade design. A stepwise testing strategy for new blade designs is normally employed, where in turn blade materials, structural samples, blade sections and complete blades are tested under fatigue and extreme loads in order to verify design and ensure sufficient strength. Repeatable blade quality and manufacturing time are two critical considerations during blade manufacture.
Components	Glass fibre, in mat and/or prepreg form. Carbon fibre (in some cases; generally in prepreg form). Resin, either epoxy or polyester. Adhesive. Closed-cell foam or balsa bulk fill. Consumables.

T2.1.2. Blade root	
Function	The blade root acts as the interface between the main composite section of the blade and the steel blade bearing.
Cost	It makes up of the order of 20% of the blade cost.
Suppliers (examples only)	An integral element of a blade design, blade roots are designed then manufactured by the blade supplier using bought-in items.
Key facts	The design of the connection to the blade bearing [T2.3.] is critical due to the attachment of a relatively soft composite structure to the stiff bolting and bearing structure. A number of different arrangements are used to provide threaded connection for fasteners connecting the blade bearing. In some cases, a ring is set into the root of the blade. In other cases, inserts are either bonded into holes drilled in the root or inserts are infused during manufacture. Finally, other designs use a single or double row of “IKEA-type” threaded bars, set perpendicular to the direction of orientation of studs. The composite structure near the blade root is designed to apply even loading around the blade root as well as smooth transfer of load into each insert. The root of the blade must be sufficiently flat so as not to apply excessive uneven load to the blade bearing. Loading of the root-end and fasteners at the blade root is critical due to the complex geometry, especially of the hub and bearing under load. Development testing of root end strength is common.
Components	Metal inserts. Composite structure.

T2.1.3.Lightning protection	
Function	Lightning protection systems provide a level of protection for the blades and the rest of the turbine.
Cost	Lightning protection is a relatively low cost but an important consideration during the design of the blade.
Suppliers (examples only)	An integral element of a blade design, blade roots are designed then manufactured by the blade supplier using bought-in items.
Key facts	Different suppliers have different strategies for the capture and transfer of high currents at high voltages from point of impact through to the hub and rest of the turbine, depending on blade materials and aspects of blade design. Lightning receptors are normally fitted at the tip and other points on the blade. In some cases, a conducting mesh is incorporated into the structure of the blade. It is generally considered advantageous not to allow lightning to pass through blade bearings and into the hub and hence to the main structural loadpath to tower base. In some cases, systems are used to gather data about the severity of lightning strikes. Such data is in some cases available by manually exchanging and reading a recording card.
Components	Lightning receptors. Lightning conductor arrangement. Data capture.

T2.2. Hub casting	
Function	The hub connects the blades to the main shaft.
Cost	A hub for a large 5MW turbine costs of the order of £80k, machined and painted.
Suppliers (examples only)	Felguera Melt, Fonderia Vigevanese, Metso, MeuselWitz, Rolls Royce, Sakana, Siempelkamp, Vestas, Eisengiesserei Torgelow and Gusstec, though only a subset can make the largest of hubs.
Key facts	The hub is made of SG iron and has mass up to around 30-40 tonnes. It houses the pitch system [T2.4.] and provides stiffened support for the blade bearings [T2.3.]. Generally, hubs are approximately spherical, with offset inner and outer surfaces to provide additional strength at the rear of the hub around the connection to the main shaft [T1.3.]. Openings are provided for personnel access. Lifting points for use during installation, support locations for pitch system components and other auxiliary systems and blind tapped holes are generally required. SG iron is typically of grade EN-GJS-400-18U-LT, cast without the need to heat-treat. SG iron is chosen above cast steel due to superior pouring and shrinkage properties. Careful development of the feeder system and design of the sand and core boxes is critical to ensure repeatable quality during manufacture. Detailed company-specific quality requirements generally are imposed.
Components	Casting. Non-destructive testing. Machining. Painting.

T2.3. Blade bearings	
Function	The blade bearings enable adjustment of blade pitch angle to control power output from the turbine, minimise loads and start/stop turbine as required.
Cost	A blade bearing for a 5MW turbine costs of the order of £40-50k.
Suppliers (examples only)	IMO, Liebherr, Rollix, Rothe Erde and SKF, all based on the continent. Rothe Erde has a subsidiary, Roballo, able to carry out certain processes in UK.
Key facts	Bearings are typically double-row 4-point contact ball bearings made from forged rings of around 3-3.5m diameter, typically of a 42CrMo4 steel, quenched and tempered. Balls are typically material 100Cr6. Total bearing mass may be up to 5 tonnes. Other designs with rollers rather than balls have been used. Raceways are hard-turned or ground after induction hardening. Bearings see a complex, reversing load pattern and operate with long periods of reversing movement over only a few degrees. Recent developments in pitch control algorithms have in some cases increased blade bearing duty significantly. It is critical to ensure relatively low friction torque to enable safe shutdown of the turbine via 90˚ pitching movements under all conditions. Some designs incorporate gear teeth to mesh with a pitch drive. Bearings are typically metal sprayed and/or painted. Relatively soft support structures and high loading lead to significant deflections of bearings during operation. Special greases have been developed in response to lubrication issues due to the high loading and intermittent movement experienced by blade bearings. Seals are rubber extrusions but with complex cross section in order to retain grease whilst minmising friction.
Components	Forged rings, machined, hardened and surface finished. Balls. Seals. Grease.

T2.4. Pitch system	
Function	The pitch system adjusts the pitch angle of the blades to control power output from the turbine, minimise loads and start/stop turbine as required.
Cost	A complete pitch system for a 5MW turbine costs of the order of £100 to £150k.
Suppliers (examples only)	See details of hydraulic and electric systems, below.
Key facts	Pitch systems are either hydraulically or electrically operated, with little external difference in functionality. Typically, blade pitch angle is adjusted almost constantly in medium-to-high winds in order to regulate rotor speed whilst the turbine is extracting maximum (rated) power. Adjustment is over a range of approximately 20° and may be at rate of up to a few degrees/second. In lower winds, the pitch system operates to maximise aerodynamic efficiency, which requires significantly less movement. The pitch system incorporates a fail-safe function to enable the blades each to be pitched quickly through 90° in order to move them from providing power to the turbine to acting as a brake. This action must be independent for each blade to avoid a single failure causing catastrophic damage to the wind turbine and must not rely on grid power. In some cases, blade pitch angles are adjusted independently to different angles on each blade in order to minimise aerodynamic loading on the rest of the turbine. Power and control signals for the pitch system are provided from the nacelle [T1.] through a bore in the gearbox [T1.4.] and main shaft [T1.3.].
Components	Either hydraulic pitch system [T2.4.1] or electric pitch system [T2.4.2]

T2.4.1. Hydraulic pitch system	
Function	The pitch system uses hydraulic actuators to adjust pitch angle of the blades.
Suppliers (examples only)	AVN Hydraulic, Bosch Rexroth, Fritz Schur, MOOG and Parker.
Key facts	Hydraulic actuation uses linear hydraulic cylinders, typically controlled by proportional valves. These actuators are generally trunion-mounted to the hub and a plate fixed to the inner (rotating) ring of the blade bearing. Maximum pressures are of the order of 250bar and total system mass is of the order of 3 tonnes. Back-up energy to facilitate safety shutdown even without grid power is provided by accumulators. The main hydraulic tank is normally located in the nacelle [T1.], with pressure and return lines passing through the gearbox [T1.4.] and main shaft along with control signals and control power.
Components	Power pack. Hydraulic actuators. Rotating union. Manifold blocks. Accumulators. Hoses. Electrical slip rings.

T2.4.2. Electric pitch system

Function	The pitch system uses geared electric motors to adjust pitch angle of the blades.
Suppliers (examples only)	SSB, MOOG and MLS.
Key facts	Electric actuation normally uses high-speed DC electric motors controlled by 4-quadrant drives, with total peak output up to around 100kW for a 5MW turbine. These motors drive blade bearings [T2.3.] via speed-reducing gearboxes and pinions meshing with either internal or external gear teeth on the blade bearing. Back-up energy to facilitate safety shutdown even in the event of no grid power is provided by batteries which are directly connected to the DC motors for a simple safety case. Blade pitch angle is measured through absolute encoders mounted on the pitch drive motors. All electric pitch items are mounted in panels or directly on the hub casting. The electric pitch system for a 5MW turbine has total mass approx. 5 tonnes.
Components	Motors. Gearboxes. Electrical panels. Batteries. Battery chargers. Position sensors.

T2.5. Spinner

Function	The spinner provides environmental protection to the hub assembly and access into the hub and blades for maintenance personnel.
Cost	Depending on size and concept, a spinner covering a large 5MW hub costs of the order of £20-30k.
Suppliers (examples only)	Bach Composites Industry and Eikboom supply fibreglass spinners.
Key facts	Generally the spinner is made from fibreglass in sections and bolted together with galvanised steel support, though some spinners are steel. Fibreglass cuffs are frequently fitted round blades to provide environmental protection to blade bearings. In some cases, personnel access is needed between the spinner and hub. Consideration is given to maintenance activities in and around the hub when designing the spinner. For a large wind turbine, the spinner may be up to 6m diameter.
Components	Fibreglass mouldings. Fabricated steel support frame.

T2.6. Rotor auxiliary systems	
Function	Auxiliary systems may be incorporated to lubricate bearings and provide condition monitoring and advanced control inputs.
Cost	Depending on the scope, auxiliary systems cost between £3k and £10k.
Suppliers (examples only)	Automatic lubrication systems: Lincoln and SKF. Blade load sensing: Insensys.
Key facts	Many wind turbine manufacturers have used automatic lubrication of blade bearings [T2.3.] for the last 10 years. A central lubrication pump is connected to a metering distribution system to ensure a consistent volume of grease is distributed to ports around the circumference of the bearing each day. Grease purged from the system is collected from exit ports to avoid over-pressurising seals. Some of the latest turbines also incorporate blade load measurement as an advanced control input, facilitating reduction in turbine loading, normally at the expense of extra pitch system duty. Lighting and other maintenance support features may also be provided in the hub.
Components	Automatic lubrication system. Blade load measurement system. Maintenance support features.

T2.7. Fabricated steel components	
Function	Fabrications are often required to stiffen the blade bearing support and provide a connection for hydraulic pitch system actuators. Other items are required for personnel protection, to facilitate access and maintenance activities and to provide a lightning path from the blades into the nacelle.
Cost	Depending on design, these components may costs from a few hundred pounds to £20k.
Suppliers (examples only)	These items are supplied by a range of steel fabricators and machinists.
Key facts	Stiffening plates are circular, flame-cut plates of the same diameter as blade bearings, with a ring of bolt holes and a central cut-out to provide access from the hub to the blade root [T2.1.2.]. These are metal sprayed and painted. It is harder to provide such stiffening with conventionally layed out electric systems, where the stiffness is more easily applied from the hub side. Other steelwork is of simple fabrication from box and other section, galvanised to provide corrosion protection.
Components	Steel fabrications, in some cases with significant machining. Surface treatment.

T3. Tower	
Function	The tower is typically a tubular steel structure that supports the nacelle. It also provides access to the nacelle and houses electrical and control equipment.
Cost	Of the order of £1 million for a 5MW turbine, depending on the tower height.
Suppliers (examples only)	Ambau, BiFab, Bladt, KGW, SIAG and Skykon. Some wind turbine manufacturers have in-house capability. In the UK, Skykon and BiFab have manufacturing sites. It is likely that others will establish in port locations.
Key facts	Fabricators work to designs provided by wind turbine manufacturers, often using free-issue materials (both steel and internal components). Each tower is around 80m high and has mass 200-400 tonnes, with almost 90% of the mass being steel plate and most of the rest, flanges. Towers are generally uniformly tapered, with a top diameter of the order of 4-5m for a 5MW turbine and a base diameter of around 6m. Design is driven by fatigue and extreme loading plus natural frequency requirements and avoidance of bucking. The restrictions on dimensions for onshore towers caused by the cost of transportation are not relevant offshore, as long as towers are made at coastal locations. Tower height is optimised for a given project with reference to planning constraints and also by comparing additional costs for a taller tower with the additional energy generated by accessing higher winds. For some onshore applications, especially with taller towers, concrete or concrete-steel hybrid towers have been used. In general, offshore towers are not so tall but concrete towers may be used, especially with concrete foundations.
Components	Steel [3.1.]. Personnel access and survival equipment [T3.2.]. Tuned damper [T3.3.]. Electrical system [T3.4.]. Tower internal lighting [T3.5.]. Fasteners [T1.13.].

T3.1. Steel	
Function	Steel is the most commonly used material for the manufacture of towers.
Cost	Steel price is relatively volatile. In some cases, it is free issued by wind turbine manufacturers; at other times it is sourced by the tower supplier.
Suppliers (examples only)	Corus, Dillinger Hütte, Ilsenburger, Rukki, Salzgitter, Siegthaler and Thyssen. Agents are also used to source and manage supply. Hempel is a key supplier of surface finish products.
Key facts	Towers are manufactured by cutting and rolling steel plate, welding to make typically 3m "cans" then welding these to make tower sections of say 40m, with bolted flanges each end. Steel plate of grade S355J2G3 NL and thickness 10-70mm is typically used. Steel thickness is varied for each "can" in steps down to only 0.5mm in the upper part of the tower. Thickness is optimised by considering overall natural frequency of the support structure (including foundation) and fatigue life and other design drivers for each "can". Flanges are generally forged and rolled from grade S355 EN10.113-2 NL steel with weld necks in order to improve the weld fatigue class. In some cases, tower top flanges are machined post welding to ensure top flange flatness is within tolerances required for the yaw bearing. Other special steel requirements are for the door frame at the tower base, typically of grade S235 J2G3 NL. The frame needs to compensate for the cutaway of significant material for personnel access [T3.2.] at a fatigue-critical location. Once fabricated, the tower sections are then shot-blasted and painted before fit-out with other internal components before being prepared for transport and storage. Surface finish is routinely metal spray followed by high build epoxy spray and polyurethane spray finish (total approx. 250 microns).
Components	Steel plate. Steel flanges. Surface finish.

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T3.2. Personnel access and survival equipment	
Function	Safe access to the nacelle is required for most maintenance activities. Though ladders are always required, in most cases larger turbines also have an elevator. Offshore turbines are usually also equipped with offshore survival equipment in case weather conditions stop the crew leaving the turbine as planned.
Cost	Costs depend on tower height and local health and safety requirements.
Suppliers (examples only)	Elevator: Avanti, Hailo and Power Climber Wind. Fall Arrest: Avanti, Latchways, Limpet Technology and Uniline Safety.
Key facts	Elevators typically operate at rates of up to 20m/min and with load capacities of between 240 and 500kg, though elevators with higher capacity have been used in order to simplify maintenance procedures. Ladders are generally of standard aluminium profile. Fall arrest devices running on rails or wires supported by the ladder and connected to body harnesses are used at all times by maintenance staff. Platforms of aluminium or steel support with checker plates are positioned to meet local health and safety requirements, providing rest points and protection from falling tools etc. Survival kits may contain distress flares, food, drink and other essentials for minimum 3 days.
Components	Fall arresters. Ladders. Elevator. Platforms, including trap doors controlled by gas struts.

T3.3. Tuned damper	
Function	In some cases, a large damper is fitted at the top of the tower in order to reduce tower loading.
Cost	Costs depend on the amount of damping required and tuned frequency. They equate to only a few percent of the total tower cost.
Suppliers (examples only)	Tuned dampers are generally made from non-specialist items.
Key facts	Typically, dampers are liquid-filled. The natural frequency of 'sloshing' is carefully tuned to have maximum effect in reducing tower fatigue loading due to varying aerodynamic loads from the rotor. Dampers can also reduce transient loads during turbine shutdowns.
Components	Support structure. Liquid container. Damping liquid (generally water-based).

T3.4. Electrical system	
Function	All wind turbines have a control panel at the tower base in order to facilitate on-site control of the turbine by maintenance staff without climbing the turbine. Many turbines use space near the base of the tower to mount various elements of the power take-off.
Suppliers (examples only)	These items are generally supplied by the turbine manufacturer to the tower manufacturer for fit-out.
Key facts	The only access to the inside of the tower base is via the access door, so if the transformer is mounted in the tower base, it is essential to be able to replace it via the door in case of failure. If sensitive electrical systems are placed at the tower base, then these are protected by a local air conditioning system.
Components	Control system [T1.7.]. Power take-off [T1.6.]. Air conditioning.

T3.5. Tower internal lighting	
Function	Lighting is provided to facilitate safe personnel access and egress from the nacelle and tower.
Cost	Costs depend on tower height and local health and safety requirements.
Suppliers (examples only)	All parts are standard, with many suppliers.
Key facts	Luminaires are frequently fitted to ladders and platforms or in some cases via magnets to the tower wall to avoid welding on lugs (hence introducing stress concentrations) in tower wall sections. In the event of loss of grid, a UPS powers emergency lighting, often a subset of standard lights.
Components	Luminaires. LV wiring. Cable trays. Emergency backup including UPS.

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4. Balance of plant

B0. Balance of plant	
Function	It includes all the components of the wind farm, outside the turbine.
Cost	Around 30% of wind farm capital costs, or £400-500 million
Key facts	The size, water depth and distance from shore of UK Round 3 projects means there is significant uncertainty in cost and considerable scope for innovation to reduce costs over time.
Components	Cables [B1.]. Turbine foundations [B2.]. Offshore substation [B3.]. Onshore substation [B4.].

B1. Cables	
Function	Deliver the power output from the wind turbines to shore.
Cost	Of the order of £80m for a typical 500MW wind farm.
Suppliers (examples only)	See relevant sections below.
Key facts	The total requirement for cables for Round 3 projects could be up to 8000km (3000km HVAC and 5000km HVDC). A single extrusion line can produce around 200km of core per year (this equates to around 40cm per minute). Due to the setup time for new lines and cable facilities, there is concern that insufficient capacity will be available to service both offshore wind and the infrastructure sector looking beyond 2015 unless new investment is made soon. Cables that will be installed subsea need to be loaded onto an installation vessel from the factory. The standard design of subsea cable used in offshore wind is made up of a stranded, profiled conductor with a combination of sealing layers, XLPE (cross linked polyethylene) insulation and armouring, giving a single 3-core cable for AC use, for example.
Components	Export cable [B1.1.]. Array cable [B1.2]. Cable protection [B1.3]

B1.1. Export cable	
Function	Connects the offshore and onshore substations.
Cost	Around £60 million for a 500MW wind farm.
Suppliers (examples only)	ABB, Nexans, NKT and Prysmian.
Key facts	Currently, most offshore wind farms are relatively close to shore and have one offshore substation with an AC export cable run to shore, although Round 2 projects in development will have more than one. An AC export is 3-core whereas a typical HCDC is of bipolar design with two single-core higher-voltage cables, meaning that for a given capacity HVDC cables are lighter with implications for the ease and cost of installation with subsequent savings in cable costs. HVAC cables suffer significant losses over longer distances due to reactive power flow. HVDC is used for long distance transmission because the full capacity of the cable system can be used for transferring active power (i.e. no reactive power flow). HVDC converter stations are expensive and the savings from the use of HVDC cable are not realised until it is around 50 miles long. Cables are laid up with insulation and armour coating around the conductors, they must have high chemical and abrasion resistance as well as tensile strength to survive the laying process. AC export cables are typically rated at 132kV but some cables have been deployed at 245kV, allowing export of 350-400MW per 3-core cable while HVDC systems can export up to 1200MW per pair of single-core cables and in time, this maximum power will increase. 132kV export cable has mass of approximately 60kg/m.
Components	Conductor. Insulator. Mechanical and chemical protection.

B1.2. Array cable	
Function	Connects the turbines to the offshore substation.
Cost	Around £20 million for a typical 500MW wind farm.
Suppliers (examples only)	ABB, JDR Cable Systems, Draka, Nexans, NKT, NSW, Parker Scanrope and Prysmian.
Key facts	Each turbine has of the order of 1 km of array cable associated with it, depending on turbine size and spacing. Inter-array cables are typically rated at 33-36kV although some developers are considering use of 66kV cabling. 33kV cable has mass of approximately 20kg/m.
Components	Conductor. Insulator. Mechanical and chemical protection.

B1.3. Cable protection	
Function	Provides protection to cables at vulnerable locations, to protect it from the wave and tidal action.
Cost	Typically around £700k for a 500MW wind farm.
Suppliers (examples only)	Trelleborg, Tekmar and Polyurethane Engineering.
Key facts	J-tube seals provide a seal at the ends of the J-tube to prevent seawater entering the J-tube. Passive seals consist of a series of disks that are pulled up into the J-tube. Active seals require inflation after they have been pulled through into the J-tube, requiring an ROV. Seals are not used in all cases, but a sealed J-tube may be filled with a corrosion inhibitor. A bend restrictor prevents damage caused by excessive bending. Cable stiffeners are also used for protection. If made from steel they effectively weigh down the exposed cable. Cable mats are also used to protect exposed areas of cable, such as when cables cross and they cannot be buried. Mats are typically made of concrete or polyurethane. Tekmar offers a J-tube-less solution for monopile foundations by providing a clamp that enables the cable to be routed through a hole the monopile.
Components	J-tube seals. Bend restrictors. Stiffeners. Cable mats.

B2. Turbine foundation	
Function	Provides support for the wind turbine and facilitates personnel access.
Cost	Foundations represent the single biggest balance of plant cost. For a 500MW wind farm with 100 turbines, the cost for foundation manufacture may be up to £300 million depending upon water depth.
Suppliers (examples only)	Design: Aarsleff, Grontmij, LICEngineering, MT Højgaard, OWEC, Rambøll and SLP. Monopiles: Bladt and SIF/Smulder. Jackets and other steel designs: Aker Solutions, BiFab Concrete: Aarsleff, NCC.
Key facts	To date, most offshore wind turbines have been supported by monopiles, either driven into the sea bed or located into drilled sockets and grouted into place if conditions require this. Design of larger monopiles is frequently driven by stiffness in order to keep the natural frequency of the complete wind turbine structure above wave loading frequencies. In shallow waters and less severe conditions, concrete gravity bases have been used successfully. The first stage of the Thornton Bank offshore wind farm used concrete gravity bases in much deeper waters off Belgium, but at relatively high cost, using 3000 tonnes concrete plus substrate ballast. Concrete material prices generally are much less volatile than steel, meaning that there may be times when they are especially attractive when steel prices are high. For larger turbines and in deeper water, the cost of monopiles rises significantly. At around 30-35m water depth, alternative designs typically are competitive, including tripods and especially jackets. For a 5MW turbine at 20m water depth, indicative mass for a jacket (including pin piles) and monopile (including transition piece) is around 600 tonnes. At 30m water depth, the jacket mass is likely to be around 800 tonnes with the monopile mass significantly higher. It is much easier to design a stiffer jacket structure for large turbines in order to meet natural frequency requirements, giving such structures the edge over monopiles. Another method that has been used on demonstration turbines for attachment to the sea bed is the suction bucket. In deeper waters still, tension leg and other floating solutions will be used. Development in UK's Round 3 zones will in most cases not require such technology. The need for innovation in deep water foundations has been recognised in the UK by the Carbon Trust, funding a foundation competition as part of their Offshore Wind Accelerator.
Components	Foundation structure [B2.1.]. Transition piece [B2.2.]. Crew access system [B2.3.]. J-tube [B2.4.]. Scour protection [B2.5.]. Sacrificial anode [B2.6.].

B2.1. Foundation structure

Function	The main foundation structure interfaces between the sea bed and the transition piece.
Cost	Materials are included in the total foundation cost.
Suppliers (examples only)	See B2.
Key facts	To date, monopiles have typically been upwards of 45m length, 4.5m diameter and mass 300 tonnes. Thickness varies along but an average of 60mm is common. In general due to increases in water depth and turbine size, these dimensions will increase. Manufacturing is simple with little work on top of rolling and welding of parallel cans. The work involved in manufacturing a jacket structure is significantly increased. The focus for suppliers now is to productionise one-off oil and gas processes in order to manufacture many more jacket structures quickly and using minimum space and labour. Manufacturing efficiency can be raised by using modular elements of constant dimensions and by using specially manufactured nodes and pre-prepared tubulars. Concrete solutions require quite different logistics and production processes. In some cases, bases have been cast on barges ready for onward transport to site.
Components	Steel plate (for monopiles). Steel tubulars and cast steel nodes (for Jackets). Rebar and concrete (for gravity bases).

B2.2. Transition piece

Function	The transition piece provides the connection between the foundation and the tower, typically finishing around 20m above mean sea level.
Cost	Usually included within the foundation contract, a transition piece will cost of the order of £500k.
Suppliers (examples only)	It is usually manufactured by the same supplier as the foundation or a coastally located tower supplier.
Key facts	The transition piece is made of steel. It is generally grouted to the foundation in order to enable correction of any deviations from the vertical in the foundation. Drilled monopiles can have a transition piece integral to the monopile. Surface protection is key, especially around the splash zone. The transition piece also provides a platform with guard rails and supports the crew access system and J-tube(s). It may also enclose the turbine transformer and a personnel refuge.
Components	Steel work, including the anode ring, personnel access, platform and the J-tube. Vessel docking interface. Davit or similar light crane.

B2.3. Crew access system	
Function	It enables operations personnel to gain safe access to the turbine platform.
Suppliers (examples only)	Steelwork is part of the transition piece. Generally other tooling is part of the service vessel.
Key facts	Adverse weather conditions can limit access to turbines and delay essential maintenance, leading to lost revenue. Currently, standard vessels are typically only able to offload crews in wave heights of 1.5m. Some turbines have systems to enable helicopters to drop crew but if used routinely, this is an expensive solution with health and safety concerns. New access systems are being developed that enable access in a wider range of sea conditions and reduce the need for helicopter use. These include wave compensating mechanisms for vessels, hydraulic lifts mounted on the vessels and cranes on the turbine access platform. The Carbon Trust is supporting activities in this area.

B2.4. J Tube	
Function	It routes the inter-array cable into the foundation and into the turbine.
Cost	Transition piece supplier.
Suppliers (examples only)	It is usually manufactured by the same supplier as the foundation or a coastally located tower supplier.
Key facts	Generally a steel tube of diameter approx. 300mm attached to the transition piece extending from platform level to around 2m above the sea bed. It is frequently sealed after the cable has been pulled through – see B1.3.

B2.5. Scour protection	
Function	Protects the foundation from scour of the sea bed caused by speed-up of water movement around the foundation due to the obstruction it provides.
Suppliers (examples only)	Peter Madsen, SSCS and others with suitable vessels to handle rock placement.
Key facts	Rock is most commonly used for scour protection. For a 6 metre diameter monopile, scour protection will typically extend to 25 metres diameter. Scour protection rock often provides habitat for lobster and crab. In some cases, rocks can sink in sediment and frond mats or alternatives are required. Routine checks are needed in order to monitor the effectiveness of scour protection, to avoid risk of movement of undermined foundations structures. Scour depth can exceed the diameter of the monopile. The rate of increase in depth slows with time, such that half of the eventual stable depth of scour typically occurs within the first year or so. It has been calculated by some that the additional cost of initial scour protection and repairs over time outweighs the cost of designing to cope with the anticipated level of scour. Jacket structures are expected to be less susceptible to scour, though local scour around members will be coupled with a global scour due to the combination of co-located constructions.
Components	Rock. Scour mats. Deployment methods. Inspection activities.

B2.6. Sacrificial anode	
Function	Provides protection from corrosion through galvanic action by dissolving before other metal components. The more active metal is more easily oxidized than the protected metal and corrodes first.
Cost	Protection is low cost and can avoid excessive repair costs.
Suppliers (examples only)	There are range of suppliers to the offshore oil and gas industry.
Key facts	A sacrificial anode consists of a zinc/aluminium bar fixed to the steel structure.

B3. Offshore substation	
Function	Offshore substations are used to reduce electrical losses by increasing the voltage before export of power to shore.
Cost	Around £50 million for a single substation.
Suppliers (examples only)	Electrical components: ABB, Siemens T&D, AREVA T&D. Structure: Bladt, Harland and Wolff, McNulty Offshore and Heerema. Structural designers: Atkins and Ramboll.
Key facts	Substations are often delivered as one element of a contract to connect the wind farm to the grid. A substation weighs up to 2,000 tonnes. The platform level is about 25m above the sea and has an area of typically 800m². Typically, a single substation can support the input from around 500MW of wind turbines. Some wind farms will have more than one substation to increase security of export. Although many substations are not being used primarily as service platforms, they will still have a modestly equipped workshop. In time, it is anticipated that substations placed far from shore will have additional functions, such as providing refuge, temporary or permanent accommodation.
Components	Electrical system [B3.1.]. Facilities [B3.2.]. Structure [B3.3.].

B3.1. Electrical system	
Function	Integrates AC power output from individual turbines and transforms voltage from (say) 33kV to (say) 132kV for export to onshore substation, else converts to DC for onward transmission.
Cost	Around £30 million per substation.
Suppliers (examples only)	ABB, Siemens T&D, EDF, Areva T&D. Transformers: Above plus Tironi.
Key facts	It is anticipated that offshore substations 50 miles or more from the onshore substation will use HVDC to reduce transmission losses. HVDC systems currently only operate point-to-point and require the use of converters at each substation (onshore and offshore). ABB, Siemens and Areva have proprietary HVDC systems. Key components include: Backup diesel generator rated at around 300kW to provides power to the substation in the event of loss of high voltage feed via export cable. It also plays a role in the commissioning of the wind farm. Switchgear sets to isolate separately the array and export connections to the substation. Transformers (if AC) in order to transform to higher voltage for onward transmission. A typical offshore substation has multiple transformers to improve the availability. Transformers are oil-cooled, requiring the use of fire and blast protection. Converters (if HVDC) in order to convert to DC for onward transmission. Reactors to improve stability of the local grid system. Earthing to provide an excellent electrical connection between the electrical components and the substation structure. Panels, cable trays, tracks, clamps and supports to protect electrical items.
Components	Backup generator. Switchgear. Transformers (if AC). Converters (if HVDC). Reactors. Earthing materials. Panels, cable trays, tracks, clamps and supports.

B3.2. Facilities	
Function	Support the operation and maintenance of the substation and wind farm more generally.
Cost	Supplied as part of the substation.
Suppliers (examples only)	Crane: Kenz Figee Fire and blast protection: Mech-Tools (steel) and SCS (composites). Supply of general facilities is often local to assembly of the substation.
Key facts	Fire and blast protection is required because the transformers contain oil and coolants and present a fire risk. They need to be protected from fires elsewhere on the platform. Since most substations have two transformers they also need to be protected from each other. Typically transformers must be protected to H60 fire protection and 0.3 Barg blast protection. Any accommodation areas need to be protected, along with escape routes. All supply is bespoke. Steel protection typically is double-skinned at up to 20cm thick with insulation, corrugations and fire-resistant coatings. Composite structures are generally thinner (4-15cm). Double thickness protection will be used between the transformers. An on-board crane to lift from a service vessel typically has a load capacity of around 2.5 tonnes. Also required is a control room, accommodation, water and fuel tanks, low-voltage power supplies, navigational aids and safety system.
Components	Fire and blast protection systems. Crane. Control room. Accommodation (refuge, temporary or permanent). Water tank. Low voltage supplies. Navigation aids. Fuel tanks. Safety system.

B3.3. Structure	
Function	Provides support and protection for the electrical and other systems.
Cost	Around £10 million for a single substation.
Suppliers (examples only)	Structure: BiFab, Bladt, Harland and Wolff, Heerema and McNulty Offshore. Helipad: Bayards, Aluminium Offshore and other suppliers to the oil and gas industry.
Key facts	The steel structure is complex, with many safety considerations and services incorporated. For a small substation, the foundation may be similar to a turbine foundation [B2.], but with a different loading pattern. For a large substation, distributed piles or a jacket is preferable. A helipad is generally specified to enable helicopter landing. Offshore helipads are generally aluminium to minimise corrosion and weight. An accident during take-off or landing can result in hundreds of litres of jet-fuel spilling from ruptured fuel tanks so stringent safety regulations are in place with the requirement for an integrated firefighting system. The use of helicopters for single-crew transfer is not expected to be routine. Access by vessel is similar to that for a turbine.
Components	Foundation. Helipad. Platform access.

B4. Onshore substation	
Function	Transforms power to grid voltage, say 400kV. Where a high voltage DC export cable, the substation will convert the power three phase AC.
Cost	Around £40 million, approximately half of the cost of the offshore substation.
Suppliers (examples only)	They are generally contracted to the same company as the offshore substation [B3.]. Typically they are jointly owned by the wind farm owner and the relevant grid operator.
Key facts	Many of the electrical components will be similar in specification to the offshore substation. There are the same constraints with weight and space as the offshore substation. The substation will contain metering equipment to monitor the input to the grid.
Components	Similar electrical systems to offshore substation [B3.1.]. Buildings and other facilities are simplified compared to offshore [B3.2.]. Metering equipment.

5. Installation and commissioning

I0. Installation and commissioning	
Function	All installation and commissioning of balance of plant and turbines, including land and sea-based activity.
Cost	In total, around £400 million for a typical 500MW wind farm.
Suppliers (examples only)	Installation: Suppliers listed in relevant sections below plus management contractors including Fluor and KBR.
Key facts	Today, the typical process for installation is to install foundations and cables in separate processes one year then install and commission turbines the next year. In time, it is likely that other strategies will be developed, especially in deeper waters much further from shore as in UK Round 3. The opportunity for innovation to reduce costs is significant. Already, the season for installation is being extended, even though this increases weather downtime. Developers vary in strategy but contracts are usually let for the cable-laying (export and array), substation installation, foundation installation and turbine installation.
Components	Export cable-laying [I1.]. Foundation installation [I2.]. Array cable-laying [I3.]. Construction port [I4.]. Offshore substation installation [I5.]. Sea-based support [I6.]. Turbine installation [I7.]. Commissioning [I.8].

I1. Export cable-laying	
Function	Installation of the cable connecting the onshore and offshore substations.
Cost	Around £80 million for a 500MW wind farm, depending on distance to shore and sea bed conditions.
Suppliers (examples only)	Global Marine Systems, Nexans, Prysmian, Subocean and Visser & Smit.
Key facts	Export cables are laid in as long sections as possible, of up to 70km in length, to avoid subsea connections. Cables are typically buried to 1.5-3m below sea bed to avoid disturbance, for example by fishing vessels or ship anchors. Simultaneous lay and burial using a cable plough [I1.2.1.] is normal for a variety of soil conditions. This is likely to be preferred. A two-stage process may also be undertaken. Here a cable is laid on the sea bed, after which a trenching ROV [I1.2.1.], supported by a trenching vessel [I1.1.], undertakes the burial. Export cable-laying is viewed as a significant constraint with a limited number of vessels currently available and few companies with the expertise. Carousel capacities of up to 7000 tonnes of cable are available, capable of carrying up to 70km of export cable. Cables have proved a problem area through damage to cables either during or after laying, leading to several significant insurance claims.
Components	Trenching vessel [I1.1.]. Cable-laying vessel [I1.2.].

I1.1. Trenching vessel

Function	Undertakes cable burial post laying of the cable on the sea bed.
Cost	Daily charter rates are in the order of £75k to £90k.
Suppliers (examples only)	Trenching vessels are provided by a number of offshore vessel operators.
Key facts	Vessels are typically 90m DP2. Post-lay burial is undertaken using a trenching ROV [I1.1.1.] using a high pressure jetting system to fluidise the sea bed and allow the cable to sink to the required depth. Jetting sleds can also be utilised.
Components	Trenching ROV [1.1.1].

I1.1.1. Trenching ROV

Function	Uses specialist equipment to form a trench in which to lay and bury the cable.
Cost	Included in the trenching vessel cost.
Suppliers (examples only)	Provided by the trenching contractor. Manufacturers: IHC Engineering Business , Perry Slingsby, SMD
Key facts	A high pressure jetting system is used to fluidise the sea bed and allow the cable to sink to the required depth. Jetting sleds can also be utilised. Cutting systems are used to form a trench in clay or rock sea bed.
Components	Power supply. Propulsion system. Control system. Pressure and flow water jetting system. Lighting system. Trench cutter.

I1.2. Export cable-laying vessel	
Function	Lays the cables between the offshore and onshore substation.
Cost	Daily charter rates are from £75k to £125k depending on vessel size and capability.
Suppliers (examples only)	Global Marine Systems, Nexans, Prysmian, Subocean and Visser & Smit.
Key facts	Historically, cable installation has been undertaken with barges equipped with a carrousel, tensioners and haulers. Array cables at Thanet wind farm have been installed using a dynamically positioned (DP2) vessel. A dynamically positioned vessel provides faster set up and installation time and can remain on station in higher sea states and wind conditions compared with a barge. The same vessels are sometimes used for export and array cable installation, although export cable-laying vessels will typically have larger carousels to accommodate longer cables. They may need to have a shallow draft to install the cables close to shore.
Components	A carousel for cable storage, a cable installation spread, a cable plough [I1.2.1.] and a work class ROV [I1.2.2.]. Heave compensation for plough launch and recovery.

I1.2.1. Cable plough	
Function	A cable plough is normally used to simultaneously lay and bury a cable.
Cost	It forms part of the cable installation vessel daily charter rate. New ploughs cost in the order of £10 million.
Suppliers (examples only)	Provided by cable installation contractor. Manufacturers: IHC Engineering Business and SMD.
Key facts	Cable ploughs can bury cable down to 3-4m below sea bed level. The plough will generally require a tow force of approximately 150 tonnes to pull the plough through the soil. Using a barge, this force is supplied by a tow tug. For a dynamically positioned vessel, a specialist vessel with an appropriate bollard pull is required.
Components	It can have high pressure jetting nozzles at the leading edge. Skids, which maintain the plough at the required depth.

I1.2.2. Work class ROV	
Function	Subsea ROVs have many uses including visual inspections of subsea structures such as cable J-tubes and foundations, feeding the cable through the J-tubes and monitoring operations such as grouting of piles.
Cost	Variable depending on the application.
Suppliers (examples only)	Provided by cable installation contractor. Manufacturers: Perry Slingsby, Saab Seaeye and SMD.
Key facts	Cable installers will seek to avoid using an ROV to minimise costs. However, the use of ROVs avoids the high costs associated with the use of divers to work at depths requiring specialist equipment and extended decompression.
Components	Remote camera. Power supply. Propulsion system. Control system. Lighting system.

I2. Foundation installation	
Function	Transport and fixing of foundation in position. The process involved varies with the foundation technology employed. Monopiles typically are driven from a jack-up vessel but can be drilled and can be installed using a floating vessel. Jacket and tripod foundations may be installed by floating cranes. Gravity base foundations may use floating cranes or specialist barges to support float out.
Cost	Around £100 million for a typical 500MW wind farm.
Suppliers (examples only)	A2SEA, Ballast Nedam, Bilfinger Berger, Fluor, Geosea, Beluga-Hochtief, Jack-Up Barge, Marine Construct International, MPI Offshore, MT Højgaard, Per Asleff, Seajacks, Scaldis Salvage and SLP.
Key facts	Monopiles (up to 6m diameter) are driven into the sea bed using a hammer and anvil system before mounting transition pieces and feeding the cable into the foundation. For larger 5MW and above turbines, jackets or tripods in steel or concrete gravity foundations are typically used. For jacket and tripod foundations pin piles are driven into the sea bed and the foundation lowered onto the pile heads and grouted into position. Concrete gravity foundations can weigh significantly more (3,000 tonnes) and may be floated out to position before being sunk. The sea bed must be levelled to receive such foundations. Offshore substation foundations may be installed in a similar way to turbine foundations but are significantly larger. Cables are drawn from the sea bed through a J-tube into the foundation base to feed up to the wind turbine.
Components	Foundation installation vessel [I2.1.].

I2.1. Foundation installation vessel	
Function	Transports the foundations from the quayside fabrication facility to the site and secures them to the sea bed. Systems include self-propelled jack-up vessels, towed jack-up barges, floating sheerleg or catamaran cranes
Cost	Charter rates are in the region of £150k/day for purpose-designed jack-up vessels which cost in the region of £130 to £150 million to build. Floating cranes may cost over £270k/day.
Suppliers (examples only)	Operators: A2SEA, Ballast Nedam, Beluga-Hochtief, Geosea, Jack-Up Barge, Marine Construct International, MPI Offshore, DBB, Scaldis Salvage and Seajacks. Vessel manufacturers: generally in the Far East.
Key facts	To date, the vessel of choice for monopile installation has been the self-propelled jack-up (e.g MPI Resolution). These can be up to 140m long and 45m wide, with a 6m draft and steaming speed up to 11 knots. The jack-up legs allow operation in depths of up to 40m. Floating cranes such as Samson, Rambiz and Stanislav Yudin have also been used for jacket, tripod and GBS foundations. Vessels have a range of onboard tooling, depending on type of foundation to be installed. For monopiles, on-board hammer and anvil systems are used to drive the piles. On-board drilling systems are used where hammering is not possible due to ground conditions or environmental restrictions. Monopiles are then grouted into position. To assist with positioning monopiles, an upending tool can be used to help lift, rotate and lower the pile into position on the sea bed. A handling tool is used for guiding the pile during pile driving. On-board crane capacity for new build jack-up vessels is typically around 1,000 tonnes. Larger floating cranes have greater capacity with Rambiz up to 3,000 tonnes.
Components	On-board crane. Dynamic positioning. Propulsion systems. Jack up system. Specialised foundation installation tooling.

I3. Array cable-laying	
Function	Installation of the power cables between the turbines and the offshore substation.
Cost	Around £60 million for a 500MW wind farm.
Suppliers (examples only)	CTC, Global Marine Systems, MPI, Subocean and Visser & Smit.
Key facts	Cables may be laid in a spider arrangement with a small number of turbines connected to a single cable that provides the connection to the substation, or in a series of chains with around 6 to 10 turbines on each. It is often not possible to plough close to the turbine and substation. A trenching ROV [I1.1.1.] may be used to bury the cable close to these structures. MPI has introduced a remotely operated subsea cable-laying "tractor", which can carry the 1km stretch of cable required between turbines, laying and burying it as it goes. It is equipped with a chain cutter and jetting tool.
Components	Array cable-laying vessel [I3.1.].

I3.1. Array cable-laying vessel	
Function	Lays the power cables between the turbines and the offshore substation.
Cost	Daily charter rates from £65k/day to £95k/day depending on size and capability.
Suppliers (examples only)	Examples include Subocean, Visser & Smit and Global Marine Systems.
Key facts	Historically, cable installation has been undertaken with barges equipped with a carousel, tensioners and haulers. Array cables have been installed using a dynamically positioned (DP2) vessel. A DP2 vessel provides faster set up and installation time and can remain on station in higher sea states and wind conditions compared with a barge.
Components	A carousel, cable tank or reels for cable storage, a cable installation spread, a cable plough [I1.1.1.] and / or a trenching ROV [I1.1.1.].

I4. Construction port	
Function	The base for pre-assembly and construction of the wind farm. Separate locations may be used for feeding foundations and the wind turbines to a wind farm. Location is critical as it affects the time spent in shipment and sensitivity to weather windows.
Cost	Around 1% of the CAPEX is spent on port-related activities during installation, between £10 and £15 million for a 500MW wind farm.
Suppliers (examples only)	UK ports used so far include Barrow, Belfast, Harwich and Mostyn. New locations are under development will face competition from the Continent.
Key facts	Construction port requirements are typically: At least 8 hectares suitable for lay down and pre assembly of product; Quayside of length 200–300m length with high load bearing capacity and adjacent access; Water access to accommodate vessels up to 140m length, 45m beam and 6m draft with no tidal or other access restrictions; Overhead clearance to sea of 100m minimum (to allow vertical shipment of towers); and Sites with greater weather restrictions or for larger scale construction may require an additional lay-down area, up to 30 hectares. A typical construction port is Mostyn in North Wales. This is capable of supporting construction of up to 300MW per year Large areas of land are required due to the space taken when turbines are stored lying down on the ground. Two turbines take up nearly 2 hectares of space.
Components	Quay. Lay-down area. Cranes. Workshops. Personnel facilities.

I5. Offshore substation installation	
Function	Transfer of the substation from its quayside fabrication site and installation on the foundation. This is a heavy lift (1,000 tonnes plus) and will typically be carried out by floating crane.
Cost	Project costs vary according to the substation size and location but are of the order of £10 million.
Suppliers (examples only)	The installation often forms part of the substation supply contract. Contractors include Fluor, Hochtief, Per Asleff, Bilfinger Berger, MT Højgaard. Ballast Nedam, Geosea.
Key facts	The substation is floated out of port on a barge. This may be equipped with a heavy lift crane or a separate vessel will lift the substation onto the foundation.
Components	Substation installation vessel [I5.1.].

I5.1. Substation installation vessel	
Function	Transport and lift of offshore substation, in order to position it on pre-installed foundation.
Cost	Floating crane charter costs can be in excess of £270k/day.
Suppliers (examples only)	Bonn & Mees, DBB, Huisman, Scaldis Salvage and Seaway Heavy Lift.
Key facts	Floating cranes may be of the sheerleg or catamaran type. Heavy lift vessels used in offshore wind include Rambiz, Stanislav Yudin and Samson. Crane ratings are from 900 tonnes to over 3,000 tonnes.

I6. Sea-based support	
Function	A number of vessels are used to support the installation process. These may include crew vessels, anchor handling, barges, dive support, ROV handling.
Cost	Charter costs vary depending on vessel size, function and level of crew.
Suppliers (examples only)	Operators: Holyhead Towing, MPI Offshore, Offshore Wind Power Marine Services and Williams Shipping, Windcat Manufacturers: Alicat, Arklow Marine Services, Alnmaritec and South Boats
Key facts	Specialist vessels are used to take crew to the wind farm for installation and commissioning tasks. These are typically 15-20m catamarans. ROV support vessels are 80-100m DP2 vessels with a moon pool and deck crane. Dive support vessels have a similar specification to ROV support vessels. They may require saturation diving systems to enable lengthy and deep water (over 50m) dives.

I7. Turbine installation	
Function	Turbine installation involves transporting the turbine components from the construction port [I4.] and installing the turbine on the foundation. Installation methods vary and include assembly of turbine tower, nacelle and blades at sea through to transfer of complete turbines from land, though this method has to date only be used on a demonstration project.
Cost	Around £140 million for a typical 500MW wind farm.
Suppliers (examples only)	A2SEA, Ballast Nedam, Geosea, Jack-Up Barge, Marine Construct International, MPI Offshore, Scaldis Salvage.
Key facts	For Round 1 and 2 sites, towers have been mounted vertically on the vessel and one or more blades joined to the hub before shipment. As the market develops, more innovative solutions with purpose-built vessels are likely to emerge. Some may involve the construction of the turbine at sea, lifting nacelle and blades to the top of the tower; others will involve the transportation of fully constructed turbines to minimise the time and work content at sea.
Components	Turbine installation vessel [I7.1.]. Turbine installation vessel plant and equipment.

I7.1. Turbine installation vessel	
Function	Supports the erection of the turbine on the foundation. Similar vessels may be used to those for foundation installation. They are often designed with jack-up legs to create a rigid lifting platform.
Cost	Charter costs around £130k/day with a new build vessel costing over £150 million. Floating cranes used for lifting a complete turbine cost up to £270k/day. Up to £80 million for a 500MW wind farm.
Suppliers (examples only)	Vessels are often supplied as part of the turbine installation contract. Operators: A2SEA, Ballast Nedam, Beluga-Hochtief, Geosea, Jack-Up Barge, Marine Construct International, MPI Offshore, Scaldis Salvage and Seajacks. Vessel manufacturers: generally in the Far East.
Key facts	Few of the vessels being used for turbine installation were built for the purpose. The growth of the offshore wind industry is likely to lead to new investment in specialist vessels. A typical specification for such a vessel would be: Length: 130m, Beam 38m, Draft 5m Crew berths: 100 Crane: 1000 tonnes Tonnage: 9,300 tonnes Transit speed: 11 knots Jack-up depth: 35m No. of wind turbines capacity: 6 No. of jack up legs: 4- 6 Jack up speed: 1m/min Dynamic positioning system
Components	On-board crane. Dynamic positioning. Propulsion systems. Jack-up system. Specialised turbine transport and installation frames.

18. Commissioning	
Function	After installation, commissioning is the process of safely putting all systems to work and addressing punch lists before handover.
Cost	Costs here are typically included in the scope of supply of the wind turbine.
Suppliers (examples only)	Generally led by the wind turbine manufacturer and substation supplier.
Key facts	The key steps in commissioning the offshore substation and cabling include visual inspection, mechanical testing, protection testing, electrical insulation testing, pre-energisation checks, and trip tests and load checks. Assuming grid connection to the turbine is complete, key steps in turbine commissioning include: Check of installation activity and documentation. Energisation of all subsystems. Testing of each link in safety and emergency system chains. Exercising of all safety-critical and auxiliary systems. Slow rotation of the rotor to confirm balance and smooth operation of the drive train. Overspeed sensor and other safety-critical checks. First generation and checks on normal operation of all systems. Checks on critical components and connections after a period of attended operation, then after a longer period of unattended operation. Even after first generation, it is routine to have significant punch lists for each turbine and substation containing outstanding issues that need to be addressed before handover to the customer and O&M teams. Handover will also require demonstration of performance and reliability over an agreed length of time.

6. Operations and maintenance

O0. Operations and maintenance	
Function	Provide support during the lifetime operation of the wind farm to ensure optimum output.
Cost	Operation and maintenance (O&M) costs of the order of £25-40 million for a typical 500MW wind farm.
Suppliers (examples only)	Typically, wind turbines are under warranty for the first 5 years of their lives and manufacturers provide full O&M services during this period. After this, the wind farm owner may operate the wind farm itself, contract to a specialist services company or develop an intermediate arrangement.
Key facts	Operational support is provided 24/7, 365 days a year, including responding to unexpected events and turbine faults, weather monitoring, turbine condition monitoring plus customer and supplier interaction. Maintenance includes scheduled and unscheduled activities and requires regular transfer of personnel to the wind turbines and onshore and offshore substation. Many of the operating practices for Round 3 have yet to be fully developed since existing offshore wind farms are generally much smaller and closer to shore. Safe access to the turbines is a critical area for further focused innovation. If required, specialist staff from the turbine manufacturer will carry out major repairs. 'Availability' is the measure of the percentage of time the wind turbine is ready to produce power if the wind is blowing. Modern onshore turbines have availability of around 98%. Many Offshore wind turbines have availability of only around 90% due to lost time due to access limitations. 'Capacity factor' is the measure of the energy (MWh) produced as a percentage of the theoretical maximum that could be produced if all wind turbines ran at full power in high winds all year. For modern offshore turbines capacity factor may be as high as 40-50% compared with 30% on shore in UK; 20% onshore in less windy markets. O&M activities aim to optimise the availability and capacity factor of a wind farm whilst keeping costs to an acceptable level.
Components	Operations [O1.]. Maintenance [O2.].

O1. Operations	
Function	Monitor the performance of the wind farm and plan maintenance schedules, plus manage customer and supplier interaction.
Cost	Operation and maintenance (O&M) costs of the order of £25-40 million for a typical 500MW wind farm.
Suppliers (examples only)	The wind turbine manufacturer during the warranty period.
Key facts	The onshore control room provides access via SCADA and other systems to detailed real-time and historical data for the wind turbines, substation, met station, offshore crew and vessels. Wind farms are monitored remotely using SCADA and condition monitoring systems as well as active inspections, including of subsea infrastructure. Review of SCADA data and prognostic condition monitoring can help to time preventative maintenance before failure occurs. Careful planning of routine and unscheduled activities with due consideration of weather conditions and availability of spares and specialist vessels is critical. Systems ensure that the operations duty manager knows where all personnel and vessels are located. In addition to hardware-related activity, environmental monitoring to understand the effect of the wind farm on the local environment and wildlife is also carried out. Each turbine has a refuge and emergency provisions in case crew are stranded on the turbine. In emergency, individual turbines or the whole wind farm can be shut down remotely to allow safe access by rescue services.

O2. Maintenance	
Function	Provide routine observation, service and repair.
Cost	The first 5 years is typically under warranty.
Suppliers (examples only)	The wind turbine manufacturer during the warranty period.
Key facts	Scheduled maintenance routines improve turbine reliability and are essential for safe operation. Turbine maintenance includes visual inspection of blades and all other key components, hydraulic checking of key bolted joints, lubrication (including refilling of automatic lubrication systems), end-to-end checks on proper operation of the safety and emergency systems, replacement of consumable items (such as slip ring brushes) and cleaning. Scheduled maintenance is best done in the summer when on average access is easier and revenue loss from the turbine being stopped is less. Unscheduled maintenance is likely to be in response to turbine faults or warnings flagged by review of operational data. Routinely, if an unscheduled visit is required, then consideration is given to carrying out routine activities at the same time. Strict health and safety requirements dictate the size of vessel and maintenance crews.
Components	O&M port [O2.1.]. Technician and equipment transfer [O2.2.]. Offshore accommodation [O2.3.]. Large component refurbishment, replacement and repair [O2.4.].

02.1. O&M port	
Function	The provision of facilities from which to operate and monitor the wind farm, plus local services and fuel for vessels.
Cost	Approximately £5 million/year.
Suppliers (examples only)	The wind farm operator will establish O&M port facilities during the installation process, as many support vessels needed for this process will operate from local ports.
Key facts	Typically wind farm operators will look to use the nearest port that meets its specifications to minimise time lost due to bad weather. For wind farms more distant offshore, the use of offshore accommodation and other facilities (possibly shared with other wind farms) becomes more attractive. Office space can be shared as long as it has a secure area. Ideally the buildings are close to the quayside to minimise the time loading support vessels. Large replacement components (i.e gearboxes) are unlikely to be kept on site. A 500MW wind farm may employ up to 100 people, of which three quarters will be technicians. The availability of skilled people is a concern for wind farm owners and operators. O&M facilities need 24/7 access, 365 days a year. As well as the port facility, operators will use remote land based support, such as specific engineering advice and information and support, performance monitoring, and 24/7 control room monitoring. Uninterrupted access requires the availability of a non-drying harbour. Each support vessel will need a 20m berth. A 500MW wind farm may require the operation of around 7 vessels, depending on distance to shore. The port may need a range of different ramped and stepped access to facilitate simultaneous transfer to multiple vessels.
Components	Administration facilities and operations room. Lifting equipment, for example forklifts (600kg) and small cranes (1 tonne) to move components from the harbour to the service vessel. Workshop, with provision for hot work (including welding, angle grinders), clamping equipment, workbench areas and tool storage. Stores, with small components that do not need specialist vessels to facilitate use. Wet and dry rooms, with space for PPE. Fuel bunker, which stores fuel for helicopters and vessels.

O2.2. Technician and equipment transfer	
Function	Provide access for technicians to the wind farm, either by vessel or helicopter.
Cost	Charter rates are around £1500/day. Vessel purchase: around £1.5 million.
Suppliers (examples only)	Vessel operators: North Sea Logistics, Windcat Workboats, MPI Workboats and Turbine Transfers. Manufacturers: Alicat, Alnmaritec, Arklow Marine and South Boats. Helicopter operators: Bond Air Services. Manufacturer: Eurocopter.
Key facts	Key requirements are robust vessels that can operate in adverse weather conditions. Many wind farm operators are opting to use 20m aluminium catamarans with capacity for 12 technicians. Vessel speeds can be over 20 knots and are designed to transfer maintenance team members in comfort and safety to the wind farm ready to start work. Helicopters provide access to turbines and offshore substations or accommodation including when weather conditions prevent access by boat. They can accommodate five technicians. Typically wind farm operators will contract the helicopter operator for a number of days use a year. Turbine access [B2.3] is an area with scope for innovation. Some service vessels have adapted bows to facilitate access to the turbine platform. New solutions could include personnel lifting systems that could transfer personnel in higher sea states and wave compensating systems.

O2.3. Offshore accommodation	
Function	Provides accommodation for technicians on the wind farm site, thus reducing transit time significantly.
Suppliers (examples only)	May be part of the substation or a separate floating or founded structure.
Key facts	Offshore accommodation will become an attractive option for wind farms operators for sites further from shore. Facilities would be provided for around 30 technicians. The only existing accommodation platform, at Horns Rev 2, was constructed alongside the substation platform.
Components	An offshore accommodation facility would require many of the systems currently employed to meet the needs of personnel working on offshore substations, i.e. generators, lighting, water supply and treatment, access facilities and welfare facilities.

O2.4. Large component replacement	
Function	Replace large components such as blades, gearboxes and generators in a timely and cost effective manner.
Key facts	Design methodologies for offshore turbines facilitate easier large component repair or indeed replacement with less external intervention. On-board service cranes can in some cases lift substantial loads. Some components on turbines however need a jack-up barge to enable replacement, although smaller vessels than those used during turbine installation can be used. Exchange is carried out in one visit, followed by off-site repair. Retrofit programmes are carefully planned to ensure effective vessel utilisation taking into account repair turnaround times.

7. Further assistance and information

Information on the role of The Crown Estate and the developers of the Round 3 zones and Scottish Territorial Waters is available at **www.thecrownestate.co.uk**

The Department of Climate Change is the leading central Government Department, facilitating the deployment of offshore wind. It works to support the UK's supply chain through its UK Renewables service.
www.decc.gov.uk
www.ukrenewables.com

The British Wind Energy Association is the leading trade association representing wind energy companies. Among its wide-ranging activities is its work on helping the industry meet its requirements for a skilled workforce.
www.bwea.com

The Carbon Trust is playing a leading role in stimulating innovation in offshore wind. As well as its own public and private funds it can also advise on the RD&D landscape more generally and the role of organisations such as the Energy Technologies Institute and the Technology Strategy Board.
www.carbontrust.co.uk

The UK's devolved administrations, the English regional development agencies and their associated enabling bodies are active in stimulating the growth of the wind industry.

Advantage West Midlands:
www.advantagewm.co.uk

East Midlands Development Agency:
www.emda.org.uk

East of England Development Agency:
www.eeda.org.uk;
Renewables East:
www.renewableseast.org.uk

Highlands and Islands Enterprise:
www.hie.co.uk

Invest NI: **www.investni.gov.uk**

London Development Agency:
www.lda.gov.uk

North West Regional Development Agency: **www.nwda.co.uk;**
Envirolink Northwest:
www.envirolinknorthwest.co.uk

One North East:
www.onenortheast.co.uk

Scottish Enterprise:
www.scottish-enterprise.com

South East of England Development Agency: **www.seeda.co.uk;**
EnviroBusiness:
www.envirobusiness.co.uk

South West Regional Development Agency: **www.southwestrda.org.uk**;
RegenSW: **www.regensw.co.uk**

Welsh Assembly Government:
www.wales.gov.uk

Yorkshire Forward:
www.yorkshire-forward.com

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