Offshore Wind Japan Project

Mapping existing technology solutions to barriers identified in Japan's Offshore Wind industry

Executive Summary (1)

Background: This report lays out the key challenges that the Japanese Offshore Wind industry faces and a critical deliverable of the project that the Carbon Trust has undertaken for the British Embassy in Tokyo. The aim of the project was to identify technical and other barriers to offshore wind development in Japan by leveraging technical and operational expertise in Europe.

Japan Offshore Wind Plans and Challenges: Since the Fukushima nuclear disaster in 2011, Japan has switched its attention towards alternative sources of energy generation, particularly renewables. Given its limited geography for onshore generation and large maritime economic zone, offshore wind has emerged as a potential growth pillar for the country's energy mix. A number of recent demonstrations – both fixed and floating – are encouraging signs; however, the industry in Japan is very nascent and faces many challenges to scale up deployment. These challenges are identified by the Carbon Trust in the first deliverable of this project, "Appraisal of the offshore wind industry in Japan". Having identified the key challenges facing the industry, this deliverable maps these challenges against existing solutions from the European market.

Relevance of European Experience: Europe has taken the lead in developing offshore wind technology over the past 15-20 years, acquiring significant knowledge and expertise in the process. However, all solutions used in Europe are not necessarily applicable to Japan. Japanese site conditions are different to UK Round 3 sites, where R&D is focussing on solutions for >30m water depth and locations far from shore. While tackling deep water challenges will be common to both, the specific geotechnical and met-ocean conditions will vary, particularly given the added threat of earthquakes and typhoons in Japan. Nevertheless, there is still considerable overlap regarding the technologies employed and best practice for constructing and operating offshore wind farms.

Report Recommendations: The report identifies challenges and possible solutions across the key parts of the offshore wind supply chain. In each of these areas, the report breaks down in to more specific challenges, what the existing local solution are to address them and what European developers have deployed. The report then offers examples of deep dives into European solutions[1].

<u>Development</u>:

- A critical need is to undertake detailed wind resource and geotechnical assessments to help developers identify the most promising sites for development, and which foundation designs can be used.
- Use of floating LIDAR technologies at site-scale could help to significantly reduce costs of gathering meteorological data, particularly given the challenges of deep water sites.
- The consenting process can be improved by assigned consenting authority to one central department and streamlining environmental impact assessment regulations. Undertaking studies to better understand the impact of wind farms on marine species can support this.
- Another key local need is to gain deeper experience of operating wind farms: partnering with European companies could be a way to achieve this.

[1]The detailed version of the deep dives can be discussed with the Carbon Trust

Executive Summary (2)

Turbines:

- Achieving 95% availability is critical to help the economics of wind farms and so ensuring gearbox and electronics reliability is critical. Collaborating with European organisations to make use of their test facilities can support R&D for next generation turbines.
- Given the unique weather conditions in Japan, there is a critical need for turbines to be resistant to typhoons and impacts of corrosion. Developing a set of standards that can be adopted internationally would put Japan at the forefront of typhoon-resistant turbine design.

Foundations

- Depending on site geotechnical and metocean conditions, there are a number foundation designs from the European market which could be deployed in Japan. However, incorporating earthquake resistance, gaining accreditation by ClassNK, and demonstrating the technologies in appropriate site conditions will be crucial next steps.
- Floating technology also requires further RD&D to reduce costs to make the technology competitive with fixed structures. Reducing steel and improving mooring and anchoring systems will need to be a key area of focus.

Installation

- A lack of large installation vessels is a major bottleneck in Japan. Using vessels which can be floated out to site, possibly as an integrated structure including the turbine, could be a solution. Alternatively, companies could look to import bespoke vessels, or construct them locally.
- Given the concern regarding the impact of wind farms on fisheries in Japan, limiting noise by using novel piling methods and noise mitigation techniques could reduce the environmental impact of offshore construction.

Connectivity

- Grid capacity is a major barrier to increasing the share of renewable in the Japanese energy mix. Grid upgrades are planned, but devising a commercial model to protect developers and consumers from excessive additional will be key.
- With floating projects, developing robust dynamic cables will be a major focus, particularly as cable voltage increases for larger arrays, namely 220kV export cables.

O&M

- Optimising O&M strategies is important to reduce LCOE in offshore wind farms. While strategies will vary depending on site location, Japan can look to Europe for technologies which can accurately monitor turbine conditions to detect necessary repairs and improve the accessibility of turbines.
- For example, Japan does not yet have a wide range of access vessels and transfer systems to enable safe and year-round access to turbines so that maintenance and repairs can undertaken.

Challenge Areas

- Development
- Turbines
- Foundations
- Connectivity
- Installation
- O&M

Wind Resource Assessments

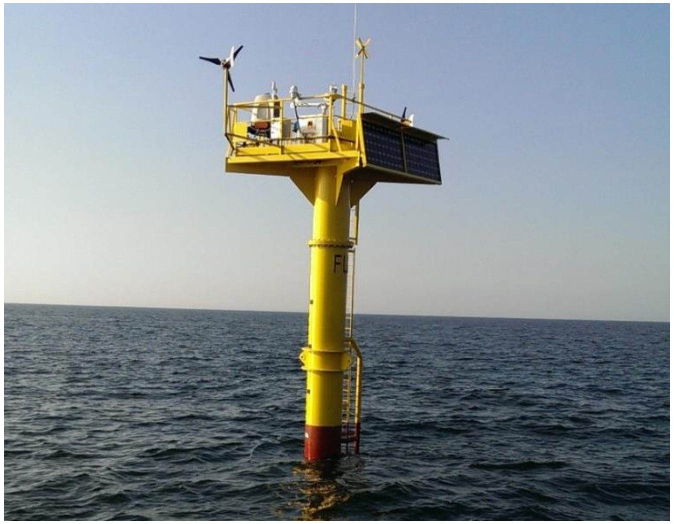
Challenge	• Need to identify best locations for offshore wind development. • Met masts are expensive and slow to install.
Existing local solution	• Satellite data has mapped wind resource around Japan. • Met masts have been installed at Choshi and Kitakyushu to collect data on met-ocean conditions. • Government departments (e.g. NEDO) have paid for met mast installation to date.
UK/European solution	1. Create wind atlas for Japan. 2. Government support for met mast deployment 3. Use LIDAR devices on existing on and offshore infrastructure. 4. Test novel Floating LIDAR.

Wind Resource Assessments

Solution 4 Example: Floating LIDAR

The Carbon Trust has supported two promising FLIDAR technologies

- Babcock Zephir
  - Floating spar buoy
  - Installed at Gwynt-Y-Mor offshore wind farm



- FLiDAR WindCube
  - Buoy platform
  - Installed at Gwynt-Y-Mor offshore wind farm

- Both systems are designed to be within an acceptable level of movement (pitch and roll motion), to ensure data is reliable and accurate.
- Self-sufficient – Power is provided by PV and micro-wind.
- Remote communication and control system reduces the need for offshore operations.
- Simple installation – no specialist vessels required.

- **Carbon Trust is now running programmes to prove the technology at various sites.**

- Additional design challenge in Japan will be to incorporate typhoon resistance.

Source: Carbon Trust (2014); www.3e.eu

Wake Effects

Challenge	• Wake effect not well understood and very little modelling is being conducted. • Very few offshore wind farms to collect real data. • Wake effects for floating wind farms will be difficult due to shifting positioning of turbine layout.
Existing local solution	None
UK/European solution	1. Fixed Bottom Arrays: Adopt the best wake effects tools from Europe and work with European companies to share wake effect data. 2. Floating Arrays: Develop suitable software for wake effect modelling of floating arrays.

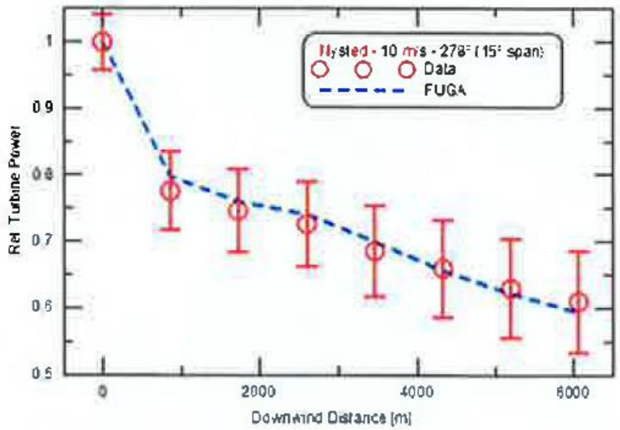
Wake Effects

Solution 1: Modelling Software used in Europe

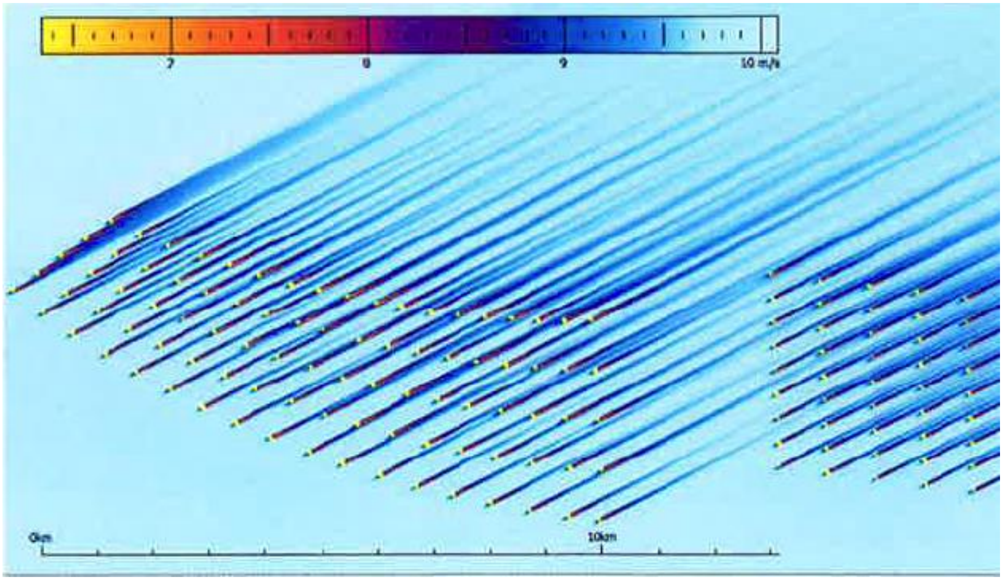
- The Carbon Trust has supported a number of wake effect modelling tools.
- One of the most promising is Riso Fuga:

Risø Fuga:

- Fast
  - 10^6 times faster than traditional models
  - Allows many more design studies to be undertaken to identify higher-yield layouts
- Model results are in good agreement with real data:



- Able to model the wind shadow of neighbouring wind farms:



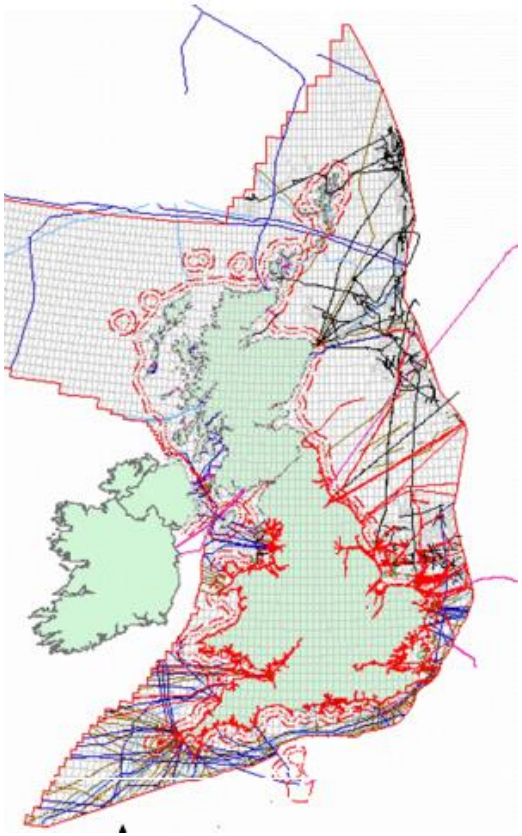
Source: DTU (2013)

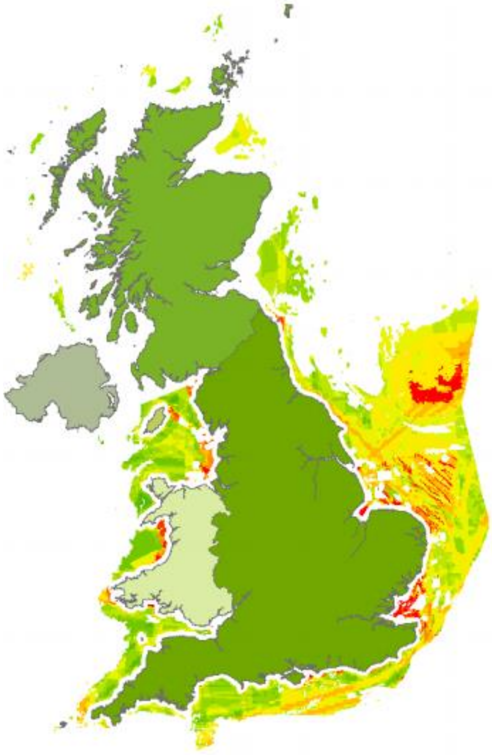
Consenting Process

Challenge	The consenting process in Japan involves various government departments. A lack of coordination can cause consenting delays. The fishing industry in Japan is very powerful and can exert considerable influence over sea use. Local fishermen have rights.
Existing local solution	• Early engagement with local stakeholders (as at Kabashima, Choshi, and Kitakyushu). • Deploy technologies around the turbine which can help to support marine life.
UK/European solution	1. Government coordination - Have one central point to coordinate government decisions for offshore wind. 2. Involve all parties early in the consenting process. 3. Spatial planning – Adopt a Geographical Information System (GIS) like The Crown Estate "MaRS" system to manage competing uses of the sea bed.

Consenting Process
UK Solution 3: Spatial Planning

- **MaRS (Marine Spatial Planning System)**
- Spatial planning GIS tool developed by the Crown Estate to identify the best sites for offshore wind development
- Ability to map:
  - Wind resource
  - Geology
  - Different sea use activities (e.g. shipping routes, conservation zones, pipelines, etc.)
- Tool can then be used to inform and optimise site selection for offshore wind farms





Source: The Crown Estate (2008) Marine Spatial Planning: A Crown Estate Perspective

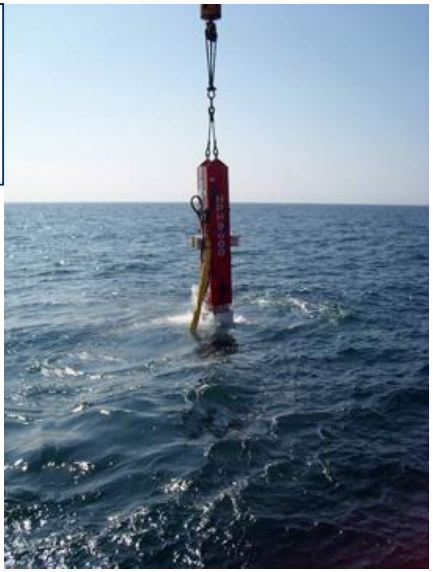
Consenting – Environmental Impact Assessments

Challenge	Environmental Impact Assessments have a big impact on consenting – they are time consuming and are a barrier to offshore wind farm development. EIAs in Japan can take 3-4 years and cost as much as $100m. Key issues are: • Piling noise • Bird collisions • Disturbance to marine mammals • Visual impact
Existing local solution	Studies on environmental impact of offshore wind turbines being conducted by MOE at Kabashima.
UK/European solution	Speed up Environmental Impact Assessment: 1. Create joint industry projects to speed-up environmental impact assessments (EIAs) 2. Run competitions to develop technologies which reduce piling noise

Consenting - Environmental Impact Assessment

Solution 1 & 2: Offshore Renewables Joint Industry Programme (ORJIP)

Noise Mitigation for Piled Hammers:
Project to identify best technology solutions for reducing the noise generated from hammer piling.

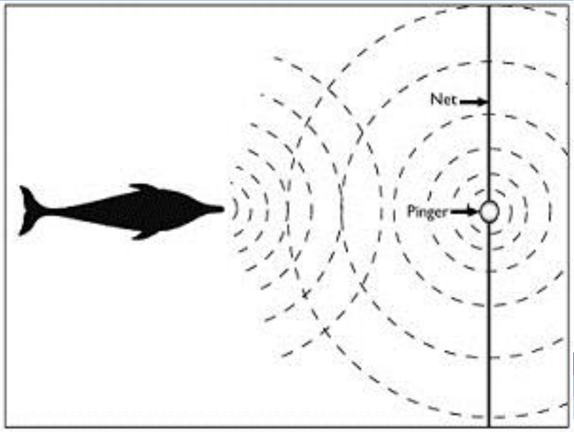


Bird Collision Avoidance:
Study to collect data on and understand bird avoidance behaviour in wind farms.

ORJIP

Acoustic Disturbance:
Study to better understand impact of hammer piling noise on marine mammals.

Acoustic Deterrent Devices:
Project to develop acoustic deterrent devices to deter marine mammals from the wind farm during construction.



Source: Carbon Trust (2014)

Lack of Project Development Experience

Challenge	Japanese developers lack experience constructing and managing offshore wind projects – only two demonstration offshore projects in Japan.
Existing local solution	Marubeni have acquired a 25% stake in Mainstream Renewable Power.
UK/European solution	1. Joint Ventures with European companies.

Challenge Areas

- Development
- Turbines
- Foundations
- Connectivity
- Installation
- O&M

Reliability

Challenge	Reliability does not appear to be a major issue; however, given the importance of availability on project economics, this is a key area, particularly as turbines become less accessible further from shore. **Gearbox:** • Challenge to develop high reliability and light gearbox. **Power electronics:** • Electrical components are prone to failures. **Testing facilities:** • There is a lack of testing facilities in Japan for large capacity turbines.
Existing local solution	In-house OEM R&D: • Mitsubishi (via Artemis) have developed an innovative DDT transmission for a 7 MW turbine. Joint ventures with foreign companies: • Mitsubishi joint venture with Vestas.
UK/European solution	1. **Gearbox:** Partner with European turbine designers and gearbox suppliers to develop capability in producing direct-drive and medium-speed geared turbines. 2. **Power electronics:** Partner with European turbine designers and component suppliers 3. **Testing facilities:** Collaborate with European companies to share test facilities.

Performance of Control Systems

Challenge	• Fault rate of power electronics is high. • Larger turbines require improved control systems to reduce loads. • Control during typhoon conditions.
Existing local solution	In-house R&D.
UK/European solution	1. Work with engineering consultancies to adopt leading control systems and build capability in-house. 2. Advanced control based on LIDAR wind measurement for independent pitch control.

Blade performance

Challenge	Larger turbines require longer and lighter blades. Most use glass fibre; likely to move to carbon fibre in future.
Existing local solution	In-house OEM R&D – developing modular blades (built in sub-sections). E.g. Mitsubishi (Eurus blades)
UK/European solution	1. Work with turbine OEMs and blade suppliers (e.g. LM, Blade Dynamics). 2. Form partnerships with European blade testing facilities.

Blade Performance

Solution 2: Blade Testing Facilities

Challenge:

- Lack of suitable blade testing facilities in Japan.

Solution:

- Europe has a number of advanced blade testing facilities:
  - NAREC (National Renewable Energy Centre – UK)
  - CENER (National Centre for Renewable Energies – Spain)
  - LORC (Lindoe Offshore Renewables Test Centre – Denmark)

- Japanese OEMs and blade manufacturers could collaborate with European companies to share test facilities and R&D learnings.
- E.g. The blades for the MHI 7 MW SeaAngel turbine, manufactured by Eurus Energy, were developed and tested at Eurus' production facility in Germany.

Narec blade testing facility

Cold climates – Ice & snow impact

Challenge	Ice forms on blades in Japan during winter, especially in OW farms in the north of the country.
Existing local solution	None
UK/European solution	1. Adopt leading European ice detection technologies. 2. Adopt leading European de-icing technologies. 3. Construct blades/rotor from icephobic surfaces.

Resistance to typhoons

Challenge	Typhoons pose potentially major threat to offshore turbines: • Blade strength - batch of onshore turbines suffered blade damage from recent typhoon.
Existing local solution	• J-Class Guidelines. • Downwind turbines. • OEMs also have designed control systems for typhoon conditions.
UK/European solution	1. Work with leading technical consultancies and blade suppliers (e.g. LM; Blade Dynamics) to better understand the loads of a typhoon on the turbine blades and tower 2. Ensure rigorous testing of blade strength in the design and manufacturing process 3. Develop control systems to adjust the pitch and yaw of turbines in typhoon conditions 4. Ensure consistency in the lifetime of components 5. Develop a set of industry standards for typhoon resistance

Resistance to typhoons

Challenge:

- Typhoons pose a major threat to Japanese wind farms
  - Example 1: In April 2013 a typhoon damaged turbines at Tsu IV onshore wind farm in Mie prefecture, western Japan. Blades broke off the turbine and the tower was damaged.
  - Example 2: All 7 turbines were destroyed on Miyako Island, Okinawa, in 2003, following a severe typhoon.

Local Solutions:

1. J-Class Wind Turbine Guidelines
   - Set of industry standards for typhoon resistance
   - Set higher specifications for parameters such as average wind speed, 50-year gusts, and turbulence
2. Downwind turbines
   - Allows blades to be less rigid and flex without striking the turbine tower
   - Downwind orientation limits interference between the rotor and the yaw sensor, ensure accurate yaw control, including free yaw during typhoons
3. Blade strength
   - Integrating more carbon fibre into blade material composites
4. Lightning resistance
   - Blades contain conductors to allow lightning current to flow from the blade to the ground without causing damage to the turbine

Challenge Areas

- Development
- Turbines
- Foundations
- Connectivity
- Installation
- O&M

Geotechnical surveys

Challenge	• The geology of the seabed around Japan is poorly understood. • Developers need to understand the seabed geology in order to understand whether a site is appropriate for OW development and select suitable foundation designs.
Existing local solution	None
UK/European solution	Conduct geo-technical surveys to assess seabed geology. Make the information publically available to inform developers of foundation design.

Foundation Design (fixed-bottom)

Challenge	• Stability: Strong ocean currents, typhoons, earthquakes, and tsunamis pose threat to stability. • Cost: Current high cost of foundations. Potential to reduce cost through using less steel and less complex designs which are less labour intensive. • Ease of installation: Current installation techniques are costly. Potential to reduce cost and improve efficiency by adopting foundations which can be installed more easily.
Existing local solution	Monopile, gravity base and high-rise pile cap foundations currently installed. Only gravity bases used beyond 1km from shore. Novel hybrid gravity-base/jacket structure installed at Kitakyushu.
UK/European solution	Optimise design of monopile and gravity base foundations and adopt leading novel designs of alternative foundation concepts from Europe: 1. Monopile (Ramboll; Ballast Nedam Concrete Drilled Monopile) 2. Gravity base (COWI; Gravitas; Gifford BMT GBF) 3. Jacket Foundations (Atkins BiFab Jacket; OWEC Quattropod; Keystone Twisted Jacket) 4. Suction bucket (Universal Foundation; Dong Suction Jacket)

Foundation Design

Solution 1: Ramboll's Monopile

- Well-suited to 0-30m water depths
- Optimised design – low cost
- Simple design – easy to manufacture
  - Suitable for automated fabrication
- Simple, well-established installation method
- Hammer piling necessary
- Low-cost solution in water depths <30m

Source: Ramboll (2013)

Foundation Design

Solution 3: Jacket foundation

OWEC Quattropod

- Complete transition piece and foundation structure
- Particularly suitable for larger turbines, deeper water, and demanding soil conditions
- Fabrication-friendly
  - Proven for serial production
- Installed in various European projects:
  - Beatrice demonstrator (2 units)
  - Alpha Ventus (6 units)
  - Ormonde (30 units)
  - Thornton Bank (48 units + 1 substation)

Source: 4coffshore.com

Foundation Design

Solution 3: Carbon Trust Foundation Competition: Keystone Twisted Jacket

Structure:

- 20% less steel than traditional jackets
- Fewer welded connections (only 9 nodes)
- Elegant transition piece
  - Uses innovative composite materials
- Suitable for varying water depth, but particularly suited to 30-60m water depth
- Design also suited to larger turbines

Installation:

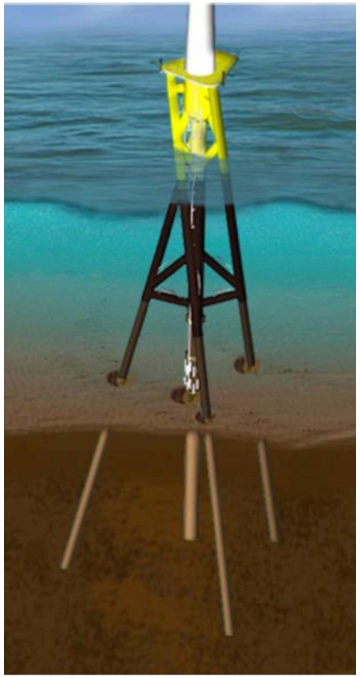
- Faster installation time
  - Fewer installation manoeuvres
  - No driving template required
- Improved utilisation of deck space increases transportation efficiency
- More units per installation vessel (double the number of a traditional 4-leg jacket)

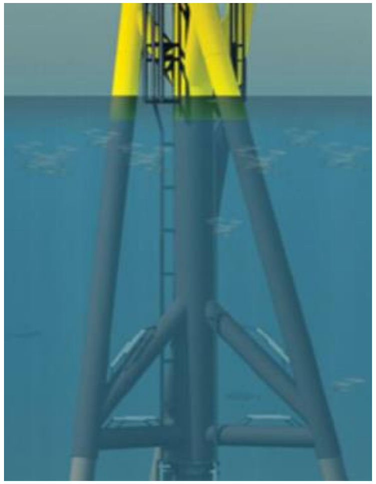
Durability:

- Unique framing arrangement and the use of raked piles allows a higher portion of the aerodynamic WTG loads to be transferred into the soils axially, allowing for a more efficient use of the soil strengths.
- Two similar designs to support drilling platforms in Gulf of Mexico installed in 2005.
- Withstood Hurricane Katrina.
- Well suited to typhoon conditions in Japan.

Manufacture:

- Fewer components and welded connections (only 9 nodes).
- Well-suited to serial fabrication.
- Safer and quicker to manufacture as it is fabricated horizontally, not vertically.





Source: Carbon Trust (2013)

Foundation Design

Solution 4: Suction Bucket Monopile

Universal Foundation (Carbon Trust Foundation Competition)

Structure:

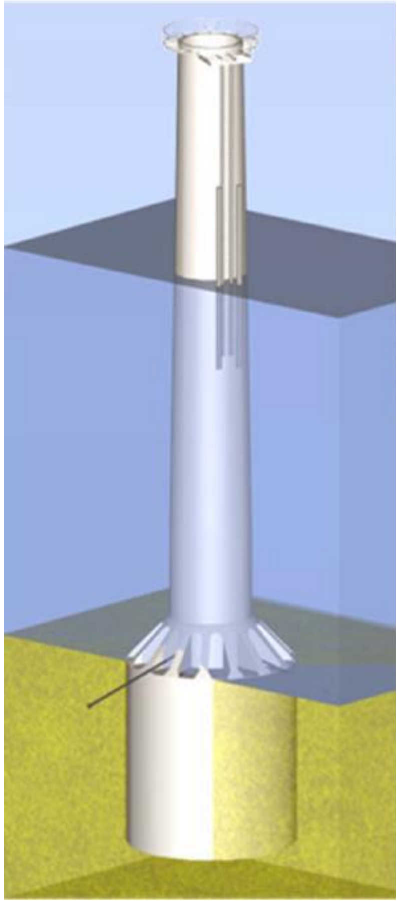
- Less steel than traditional monopiles
- Fewer offshore operations
- Smaller vessels required
  - Simpler installation as foundation towed out
- No piling
  - Removes need for transition piece
  - Low noise impact
- Less scour protection required
- Easy to retrieve for decommissioning
- **~20% cheaper than traditional monopiles**
- **~30-50% cheaper than traditional jackets**

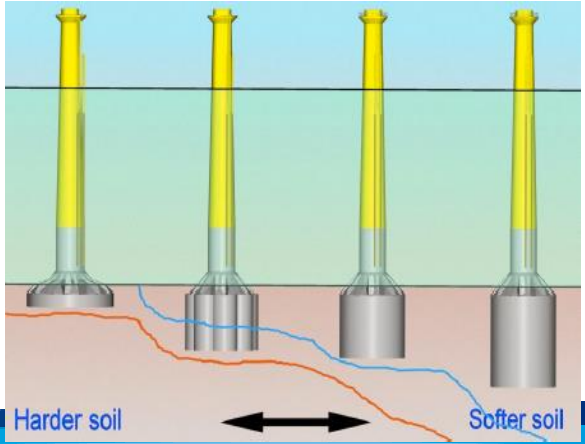
Manufacture:

- Reduced steel
- Simple geometric welded steel structure suitable for mass production
- Reduced need for scour protection

Installation:

- No seabed preparation
- The structure is upended by ballast water or by crane
- Crane is hooked on to stabilize touch down
- After initial penetration, suction is applied using snap-on pump unit aboard the installation vessel
- Can be installed in a variety of coastal conditions (0-55m depth)
- Flexibility of bucket foundation gives wider range of application
  - Sites with complex geotechnical properties can be covered by a single foundation concept





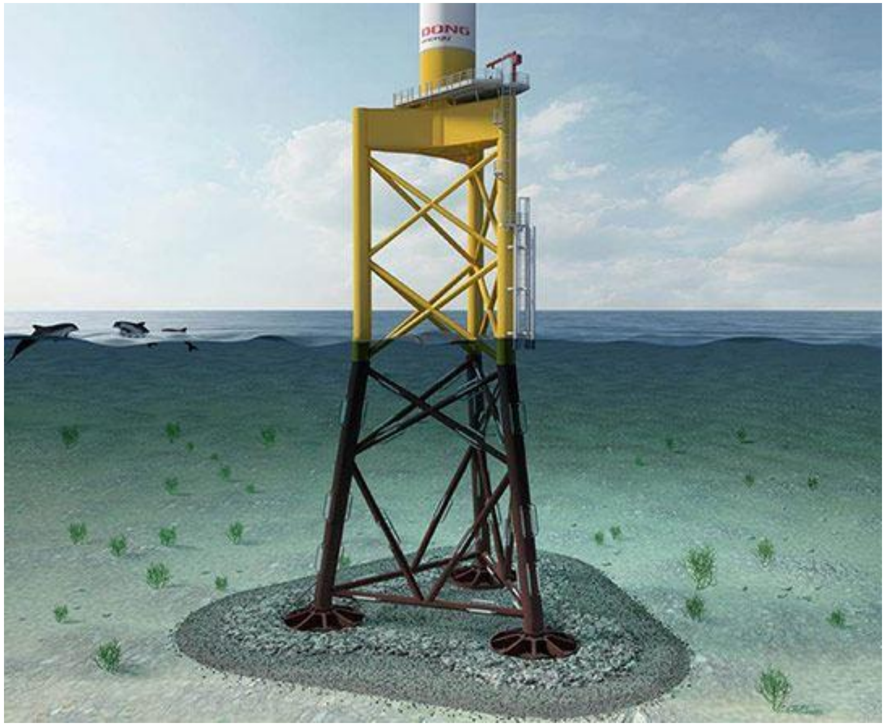
Source: Ibsen (2012) Aalborg University 9th Deep Sea Offshore Wind R&D Seminar

Foundation Design

Solution 4: Suction Bucket Jacket

Dong Energy Suction Jacket (Carbon Trust Foundation Competition)

- Combines jacket technology with the easier, quicker, and cheaper installation process of suction buckets.
- Strong stability – 3 suction buckets anchor the structure to the seabed.
- Environmentally friendly installation process – No hammer piling provides benefits regarding noise impact.
- Shorter installation time.
- Jacket is well-suited to strong ocean currents and resistance to tsunami impact.
- Full-scale demonstration funded by the Carbon Trust and Dong Energy set to be installed in 2014.
- If successful, it could be implemented in commercial projects from 2017.



Foundation Design (floating structures)

Challenge	• Identifying and proving the best floating designs. • Entering foreign markets.
Existing local solution	Japan is the world leader in floating technology, and is testing several full-scale demonstrations on different spar buoy and semi-submersible designs.
UK/European solution	1. Consider testing European concepts in Japan. 2. Test leading Japanese concepts in European waters.

Foundation Design (floating structures)

Solution 1: Demonstrate European concepts in Japanese waters

Statoil – Hywind Spar Buoy

- World's first full-scale floating structure, installed off the coast of Norway.

- Slender, ballast stabilised cylinder.
- Low water plane area to minimise wave loading.
- Simple structure to minimise production costs.
- 3 mooring lines to prevent excessive rotation around the vertical axis.
- Mooring system has inherent design redundancy, with adequate strength in case of a mooring line failure.

- Potential collaboration between Statoil and Hitachi Zosen to develop the concept in Japan.

Foundation Design (floating structures)

Solution 1: Demonstrate European concepts in Japanese waters

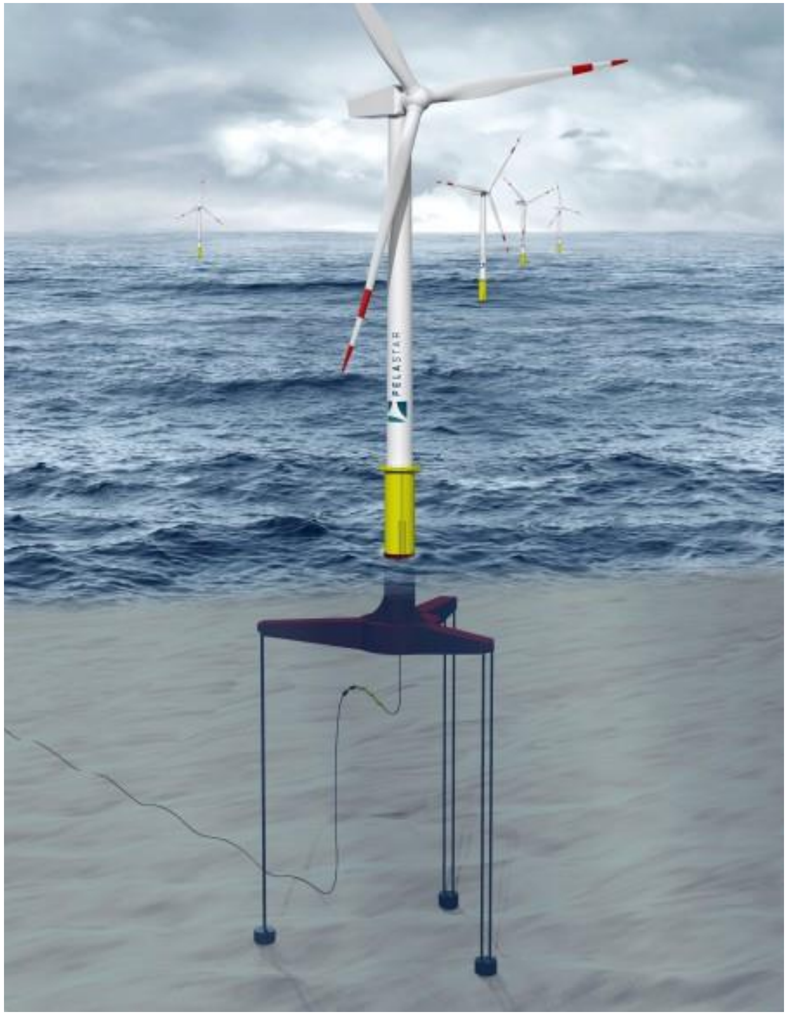
Glosten – PelaStar (Carbon Trust Foundation Competition)

- Tension leg platform (TLP) design, adapted from technologies used in oil & gas industry.

- Simple design – optimised steel structure with no mechanical systems.
- Minimal motions and accelerations at the turbine.
- Efficient quayside assembly and turbine testing reduces offshore operations.
- Low capital costs, relative to other floating concepts.

- Model testing 1:50 scale completed in 2011.
- Full-scale 6 MW turbine demo planned in the UK for 2015, followed by multi-unit pilot project in 2017.

- The design has benefitted from R&D funding support from the Carbon Trust, after making the shortlist for the Carbon Trust Foundation Competition.
- Glosten have since been awarded $6m funding from the Energy Technologies Institute (ETI) for the engineering phase of the demonstration.
- If successful, ETI will provide an additional $31m for the full scale demonstration in 2015.



Foundation Design (floating structures)

Solution 1: Demonstrate European concepts in Japanese waters

Principle Power – WindFloat

- Semi-sub floater fitted with water entrapment heave plates at the base of each column to improve motion performance.
- Mooring system employs conventional components such as chain and polyester lines to minimise cost and complexity.

- Installed off the Portuguese coast in 2011.
- Plans to build a 27 MW array off Portugal.
- Another 30 MW demonstration project is also planned off Oregon, USA.

Foundation Design (floating structures)

Solution 1: Demonstrate European concepts in Japanese waters

IDEOL

- Concrete semi-sub floater
- Concrete hull reduces material costs
- Developed and patented the Damping Pool system, which reduces floater motion by using the hydrodynamic properties of water mass entrapped in a central well.
- Oscillations are, by design, opposed to the excitation force generated by the waves.
- Developed a mechanical solution to adjust moorings and alter the orientation of the IDEOL floating turbine, which can reduce wake effects by up to 70%. (see earlier slides on wake effects).
- Planning two full scale demonstrations, with a 2 MW Gamesa turbine and 3 MW Acciona turbine, by 2015.

Modelling tools for floating structures

Challenge	• Modelling tools need to be able to simulate the whole structure's behaviour, including the interactions between the turbine, foundation, and moorings. • Lack of real data to validate models.
Existing local solution	
UK/European solution	1. Use software packages like DNV's Sesam to model whole structure behaviour. 2. Work with DNV to use real data from demonstration projects to inform software and validate models.

Corrosion

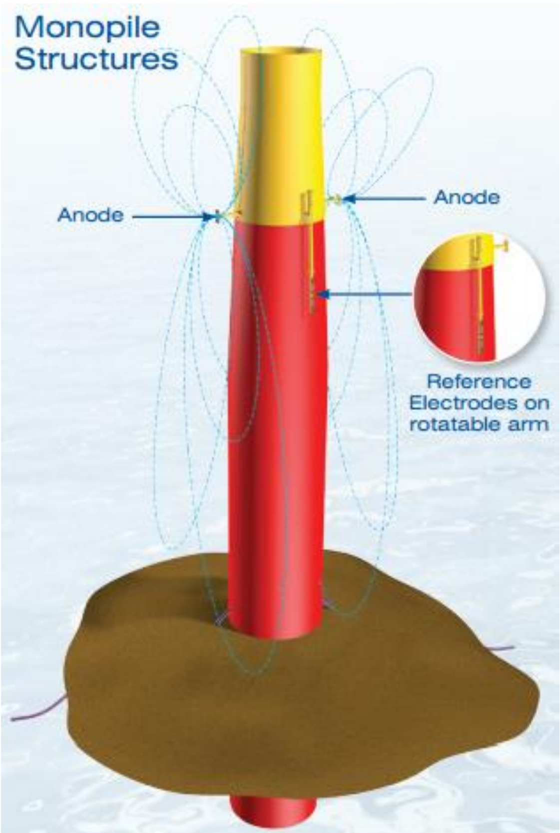
Challenge	Corrosion can negatively impact on the asset integrity of the foundation.
Existing local solution	Various coating institutes and commercial products in Japan.
UK/European solution	1. Adopt conventional anti-corrosion protection 2. Use Impressed Current Cathodic Protection 3. Use remote monitoring to detect corrosion 4. Form joint industry project to tackle corrosion 5. Partner with European companies: • Hempel (Denmark) • Cathelco (UK) • FORCE Technology (Denmark) • The Welding Institute (TWI) (UK) • TNO (Netherlands) • Local shipping industry

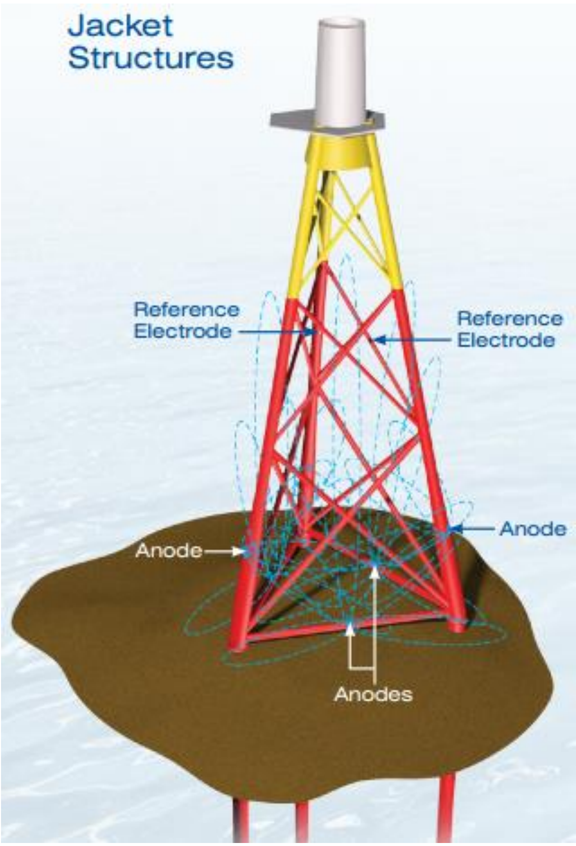
Corrosion

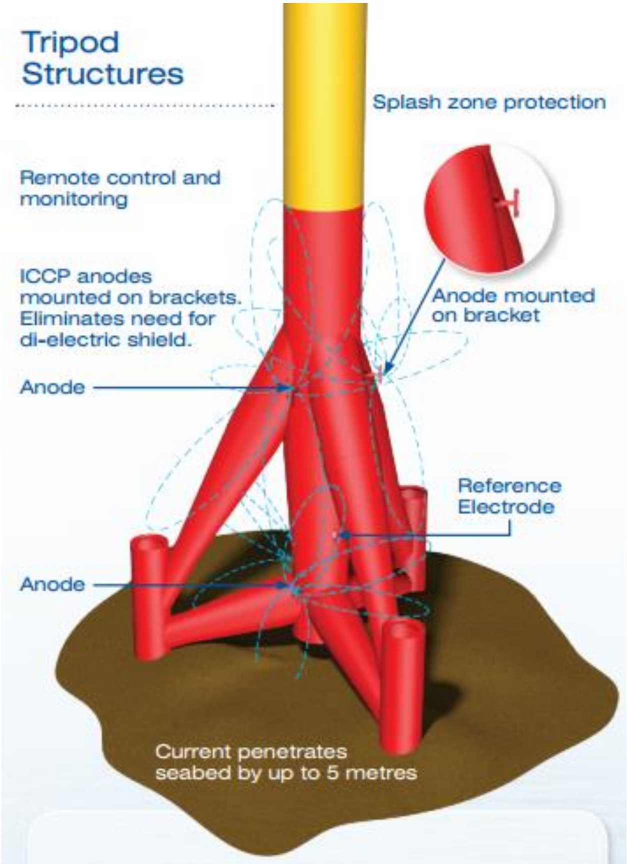
Solution 2: Active corrosion system

Impressed Current Cathodic Protection (ICCP)

- **Optimum anode configuration:** Anodes should be placed in a configuration which achieves the optimum level of corrosion protection.
- **Power:** Anodes are connected to a power source to provide enough current to protect the entire structure.
- **Control & monitoring:** Control system installed to remotely monitor system status and alter the current.







Source: Cathelco (2013)

Fatigue

Challenge	The welded joints of foundations are susceptible to fatigue.
Existing local solution	None
UK/European solution	1. Reduce the number of welded connections. 2. Introduce industry standards and certification for foundation quality. 3. Use modelling tools to improve structure design. 4. Engage with The Welding Institute (TWI) in UK.

Mooring strength and durability (floating structures)

Challenge	• Moorings of floating structures are subjected to significant stresses, and need to be able to extreme weather events such as typhoons and tsunamis. • Moorings used on the semi-sub of the Fukushima project proved to weak initially and broke several times, leading to costly delays. • Moorings need to last for the full lifetime of the turbine (at least 20 years). Replacing moorings is extremely expensive.
Existing local solution	None
UK/European solution	1. Use DNV's Sesam DeepC software to model mooring behaviour. 2. Adopt anti-corrosion solutions. 3. Share learnings with local shipping companies. 4. Develop a local Joint Industry Project (JIP) to focus on mooring performance and durability.

Challenge Areas

- Development
- Turbines
- Foundations
- Connectivity
- Installation
- O&M

Grid Capacity

Challenge	• Grid capacity is a major bottleneck to increasing renewable energy production in Japan. • Transmission capacity needs to increase significantly. • Grid upgrades are expensive, and the cost needs to be justified.
Existing local solution	• METI has commissioned a study with Hokkaido Electric Power to develop a JPY 50bn grid-expansion plan. • METI also plans to install a massive battery bank on Hokkaido to stabilise the flow of solar and wind power in the grid.
UK/European solution	1. Establish a single entity for coordinating national power transmission (e.g. UK National Grid). 2. Work with European utilities/consultancies to understand the needs for a national grid system with significant renewable energy generation.

Grid Connection

Challenge	Connection from farm to shore
Existing local solution	• Offshore wind projects in Japan to date have been government funded demonstrations. It is unclear as to which approach will be taken for connecting farms to the grid.
UK/European solution	Two different models are employed in Europe; both of which have issues: 1. Adopt super shallow model to encourage developers to enter the market. 2. Assign clear responsibility for connecting wind farms – either grid company or developer – to ensure that there are no delays in connecting the wind farm to the grid.

Offshore Substations

Challenge	Offshore substations unlikely to be needed for fixed-bottom projects, since they can be connected directly to shore, with minimal transmission losses. Floating offshore substation will be needed for floating projects (world's first floating substation installed at Fukushima in 2013).
Existing local solution	• Fixed-bottom: Turbines currently connected directly to onshore substation. • Floating: Hitachi produced the floating substation for Fukushima project.
UK/European solution	1. Work with European companies such as Siemens, ABB, and Alstom.

Transmission Losses

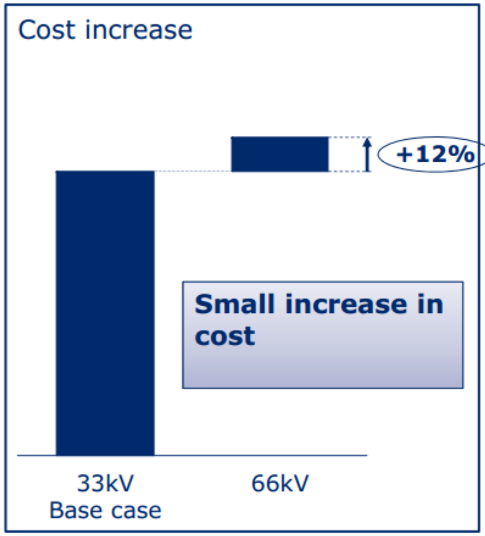
Challenge	Medium voltage arrays experience transmission losses and are vulnerable to cable failures
Existing local solution	Many farms already moving to 66kV (e.g. Fukushima).
UK/European solution	1. Move straight to higher voltage arrays (e.g. 66kV) to minimise losses 2. Use ring, rather than radial, networks to increase redundancy and reduce downtime 3. Commercialise 66kV cables

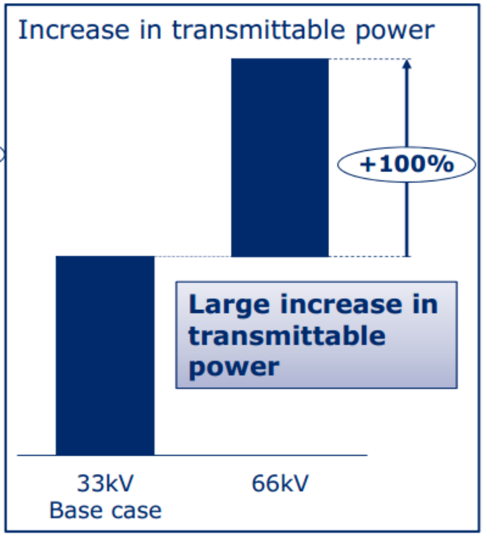
Transmission Losses

Solution 1: High voltage arrays (66kV)

- Moving to high voltage arrays (from 33kV to 66kV) can increase the efficiency and reliability of collecting and transmitting electricity.

- **Key advantages:**
  - Lower losses in array cables
  - Lower current means fewer substations are required
  - Substation transformers are lighter compared to 33kV transformers
  - Ability to connect turbine in 'loops' to improve availability (Ring network)





Connection Planning

Challenge	Inherent tendency for developers to focus FEED on foundations and turbines, and neglect cabling.
Existing local solution	None
UK/European solution	1. Conduct cable route surveys early in the planning phase. 2. Involve suppliers and contractors early in the FEED process.

Supply of Submarine Cables

Challenge	Although there are a number of cable suppliers in Japan, the market is small with limited completion, meaning that costs are high.
Existing local solution	None
UK/European solution	1. Increase local manufacturing capacity 2. Reduce the number of cables required 3. Form joint ventures with overseas suppliers

Cable Installation Vessel Availability

Challenge	• Shortage of cable installation vessels - only 1 available. Potentially large bottleneck.
Existing local solution	
UK/European solution	1. Increase production capacity of local suppliers 2. Import cable installation vessels from Europe

Cable Installation Vessel Availability

Solution 2: Import cable installation vessels from Europe

› European vessel suppliers have designed bespoke cable installation vessels to serve the European market.

› These could be imported/leased for Japanese projects, and/or the designs could be mirrored and manufactured in Japan.

Jan de Nul "Willem de Vlamingh":
- 28m diameter carousel for export cable installation
- 5,400t capacity turntable with 5t and 10t deck tensioners for array cable installation

Vuyk Cable Installer:
- Minimum draught for shallow water operations
- Compact dimensions for manoeuvrability in the field
- Two carousels – can install two cables simultaneously
- Dynamic positioning system with two azimuth thrusters at the stern and two tunnel thrusters at the bow

CT Offshore "CLV SIA":
- Largest vessel in CT Offshore fleet, serving OW industry since 2010
- Three turntables
- 55 persons

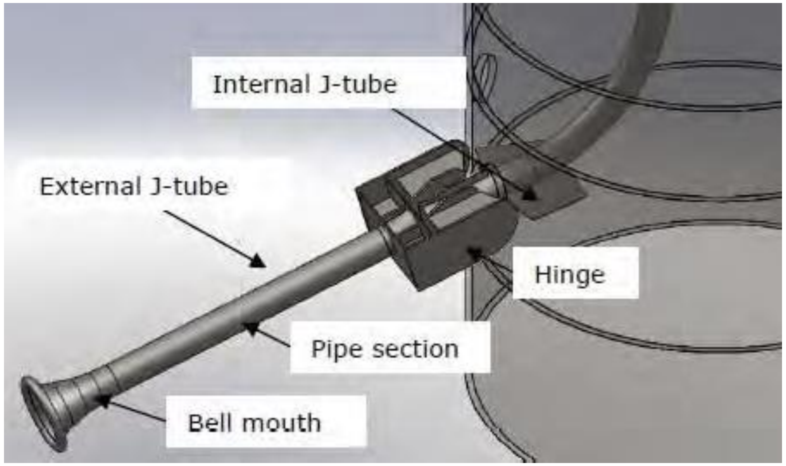
Cable Damage

Challenge	Cable damage poses major risk - ~80% of insurance claims in OW industry.
Existing local solution	None
UK/European solution	Fixed: 1. Optimal burial depth 2. J-tubeless cable installation Floating: 3. Dynamic cables

Cable Damage

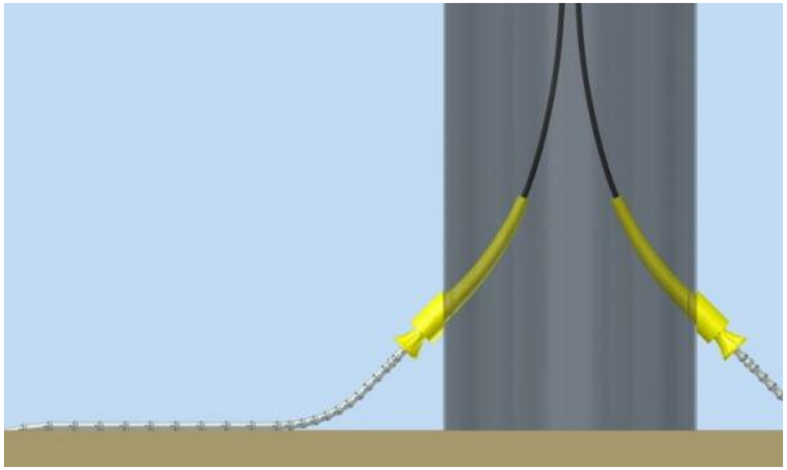
Solution 2: J-tubeless cable entry system

J-tube cable entry system[1]



- **J-tube cable entry systems widely used in offshore wind**
- **Adopted from Oil and Gas**
- **But is it the best cable entry system for offshore wind?**

J-tubeless cable entry system[2]



- **Benefits of J-tubeless cable entry systems**
  - Lower cost as less steel
  - Opportunity to improve cable installation process
  - No divers/ROVs required

1. Installation schedule for Sheringham Shoal offshore wind farm, March 2010 - Scira
2. Vos Prodect PRO-UPS Universal Pile Entry System

Challenge Areas

- Development
- Turbines
- Foundations
- Connectivity
- Installation
- O&M

Supply of Piling Hammers

Challenge	Lack local capability to produce piling hammers – currently imported from abroad.
Existing local solution	Piling hammers are imported from foreign suppliers (e.g. IHC).
UK/European solution	1. Work with international suppliers to import/build capability producing piling hammers e.g. IHC, Menck. 2. Develop vibro-hammers locally (cheaper than conventional piling hammers). 3. Adopt drilled monopile technology. 4. Adopt BLUE Piling Technology. 5. Use foundation designs that don't need to be piled, i.e. suction bucket foundations (e.g. Universal Foundation), and gravity base foundations (where appropriate to seabed conditions).

Installation Vessel Availability (Turbines & Foundations)

Challenge	• Low availability of vessels for turbine and foundation installation. • No bespoke vessels with batch installation capability.
Existing local solution	Increase production of vessels from local suppliers.
UK/European solution	1. Adopt foundation designs which are self-installing (a), or can be integrated with the turbine and floated out to site (b) to eliminate the need for large vessels. 2. Import vessels which can optimise installation by accommodating more turbines/foundations per vessel (work with international contractors like Swire Blue Ocean, Fred. Olsen, MPI, GeoSea, Hochtief, A2Sea). 3. Scale up vessel production by leveraging domestic manufacturing capability.

(1a) Smaller/cheaper vessels and (1b) Float out structures

(1a) Self-installing foundations (smaller/cheaper vessels):

- Suction bucket foundations do not require large heavy lifting vessels.
- In water depth >20m, simple tug barges can tow the foundations to site, where they can "self-install" using ballast to sink the bucket skirt and pumps to instigate the suction into the seabed.
- In shallower water depths, a small crane is required to hoist the monopile into place.
- Crane also required for turbine installation.

(1b) Float out structures:

- Float out structures also eliminate the need for large vessels, both for foundation and turbine installation.
- E.g. Gravity base foundations (Gifford BMT; Gravitas).

(2) Optimise utilisation
Turbine transportation and installation

Swire Blue Ocean "Pacific Orca"

- Largest installation vessel currently in operation
- 1,200t capacity main crane, plus 40t capacity auxiliary crane
- 4,300m^2 cargo area
- Carrying capacity: 12 x 3.6MW turbines

Vuyk FWTIV

- Able to transport and install multiple fully assembled turbines
- Floating
- Multifunctional seafastening, reducing load on turbines and vessel during transport
- Fully motion compensated 800t crane
- Ballast tank to maintain stability

Lack of installation experience

Challenge	Only two demonstration offshore projects in Japan.
Existing local solution	None
UK/European solution	1. Get international developers into projects (e.g. JVs with European developers – DONG, Statoil, etc.), and/or get international installers into projects (e.g. A2Sea, Swire Blue Ocean etc.)

Challenge Areas

- Development
- Turbines
- Foundations
- Connectivity
- Installation
- O&M

Condition monitoring systems

Challenge	Condition monitoring systems need to be improved for offshore wind turbines. Reliability data is not shared.
Existing local solution	• Transfer technology from onshore turbines. • Improve quality through in-house R&D.
UK/European solution	1. Adopt leading condition monitoring systems from Europe. 2. Engage with the Centre for Advanced Condition Monitoring, at the University of Strathclyde, and/or European condition monitoring companies. 3. Mandate sharing of reliability across industry.

Access vessels

Challenge	No bespoke vessels currently available.
Existing local solution	None
UK/European solution	1. Adopt leading European access vessel designs.

Access Vessels

Solution 1: Adopt European designs

Carbon Trust OWA Access Competition

- Speed
- Draught

Umoe Mandal
Surface Effects Ship

- Speed
- Stability at the turbine

Fjellstrand Wind Server
1st Wind Server is now in the water

- Comfort
- Stability at the turbine

Extreme Ocean – TranSPAR

- Comfort
- Stability at the turbine

Nauti-Craft
Nauti-Craft has built 8m prototype

Source: Carbon Trust (2014)

Transfer systems

Challenge	No bespoke transfer systems currently available.
Existing local solution	None
UK/European solution	1. Adopt leading European transfer system designs.

Transfer Systems

Solution 1: Use European designs

Carbon Trust OWA Access Competition

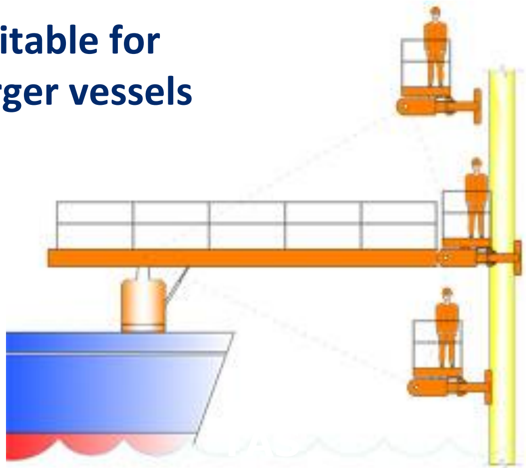
Ad Hoc Marine, Otso – Autobrow

Retrofit to commercial vessel

North Sea Logistics

Pivoting Deck Vessel

- Suitable for larger vessels



Knut Hanson – Wind Bridge

Source: Carbon Trust (2014)

Lack of O&M experience

Challenge	No commercial offshore projects in Japan.
Existing local solution	None
UK/European solution	1. Partner with European vessel operators, developers, turbine OEMs.

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