Carbon Trust
Offshore Wind Accelerator
Driving down the cost of offshore wind

24 Jan 2014

EERA DeepWind 2014

CARBON TRUST
DONG energy
e.on
MAINSTREAM RENEWABLE POWER
RWE The energy to lead
SCOTTISHPOWER RENEWABLES
SSE Renewables
Statkraft
Statoil
VATTENFALL

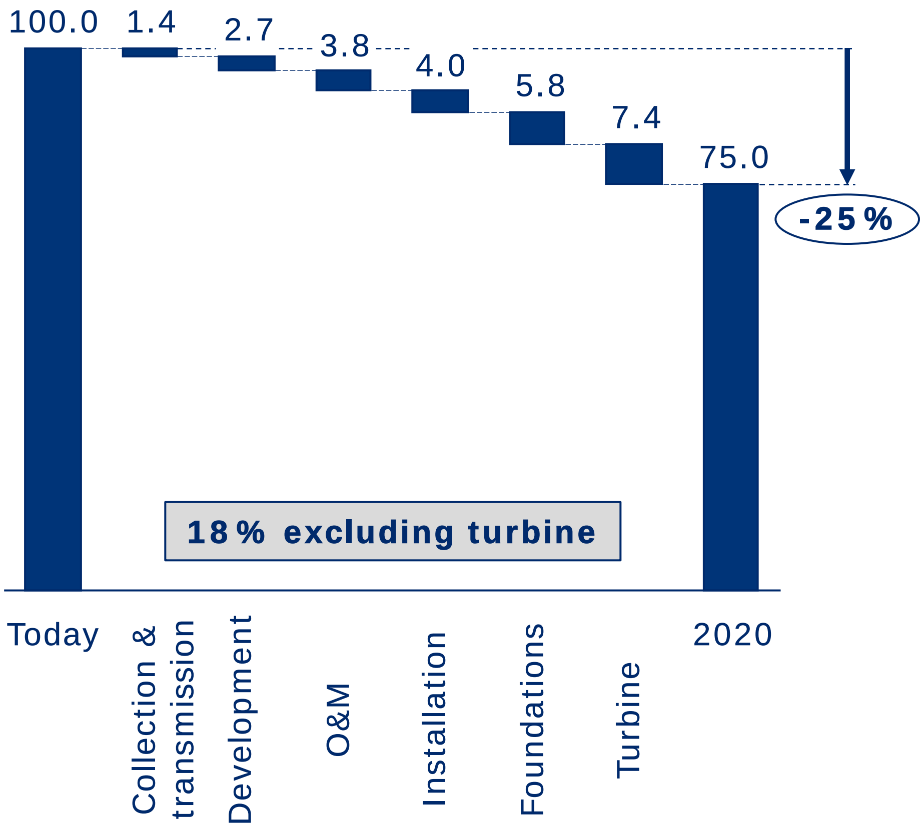
Offshore wind

Situation analysis

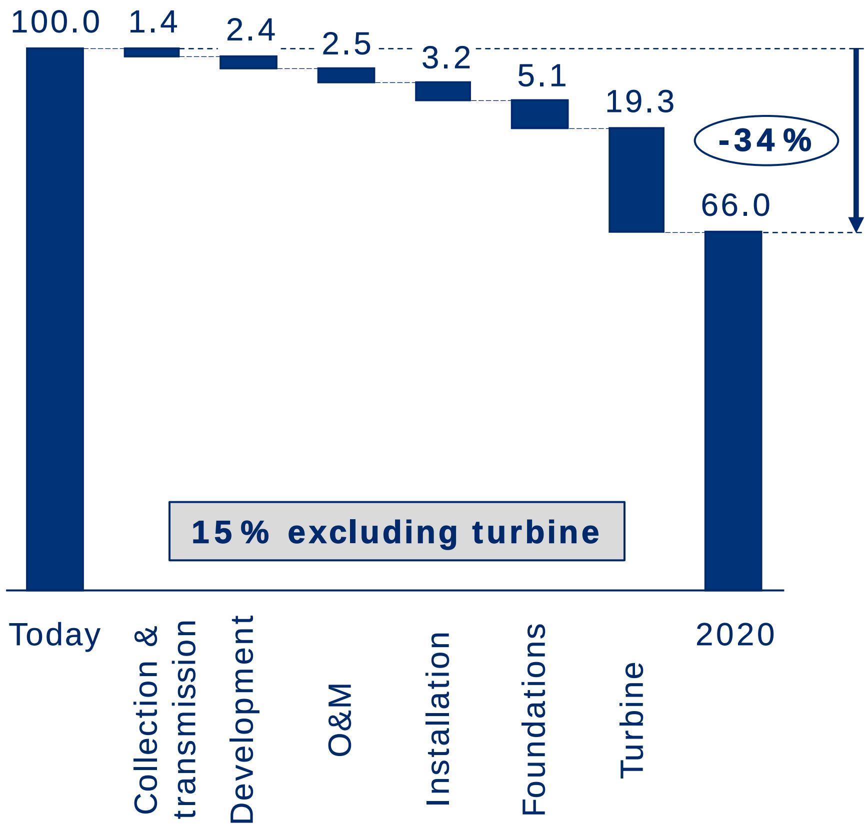
- **Offshore wind is a young industry, near the start of the learning curve**
  - 22 years old vs 75 for gas, 115 for coal
  - ~6GW installed vs 2,500GW gas, 2,400GW coal
- **Plenty of scope for cost reduction**
  - Mainly from innovation…
  - …and also from supply chain and finance
- **For a healthy, sustainable industry, costs need to come down from ~£150/MWh to ~£100/MWh by 2020**
- **If we can get innovations to market quickly, the industry can deliver significant cost reduction**

Innovation could deliver 25% cost reduction by 2020

TINA (UK waters)



TCE pathways (4 to 6MW, site B)

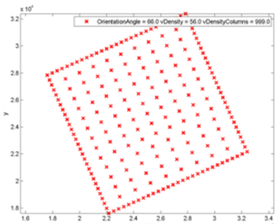
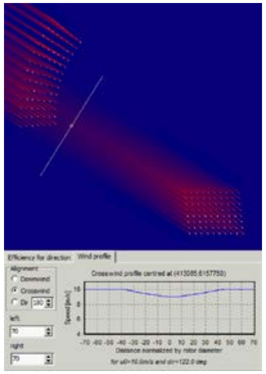


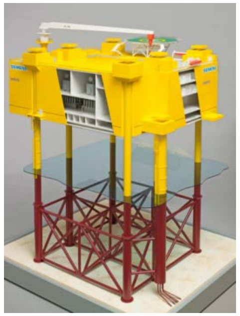
Note: TINA suggests further cost reduction is possible from turbines if there is more competition – up to ~15% LCOE reduction
Source: TINA Executive Summary 17 Jan 2012; initial TCE pathways innovation model outputs 2 Feb 2012

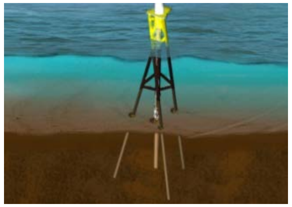
Significant opportunity for innovation to drive down costs

CARBON TRUST

Development → **Electrical** → **Foundations** → **Installation** → **Turbine** → **O&M**

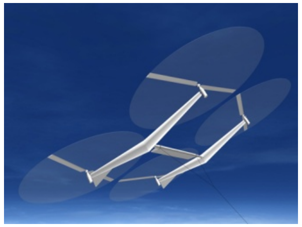
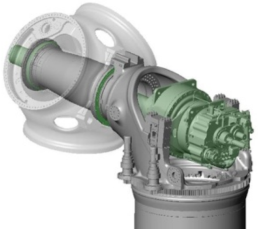
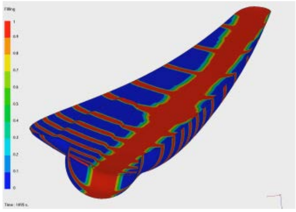







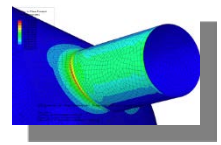
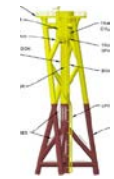
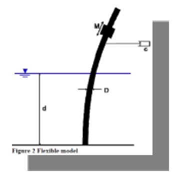
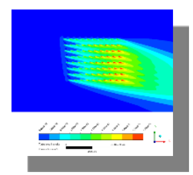
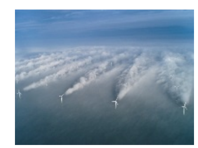
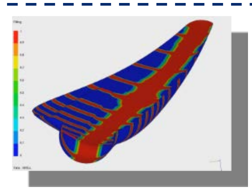




Research is critical to gain commercial benefits

We are standing on the shoulders of Giants

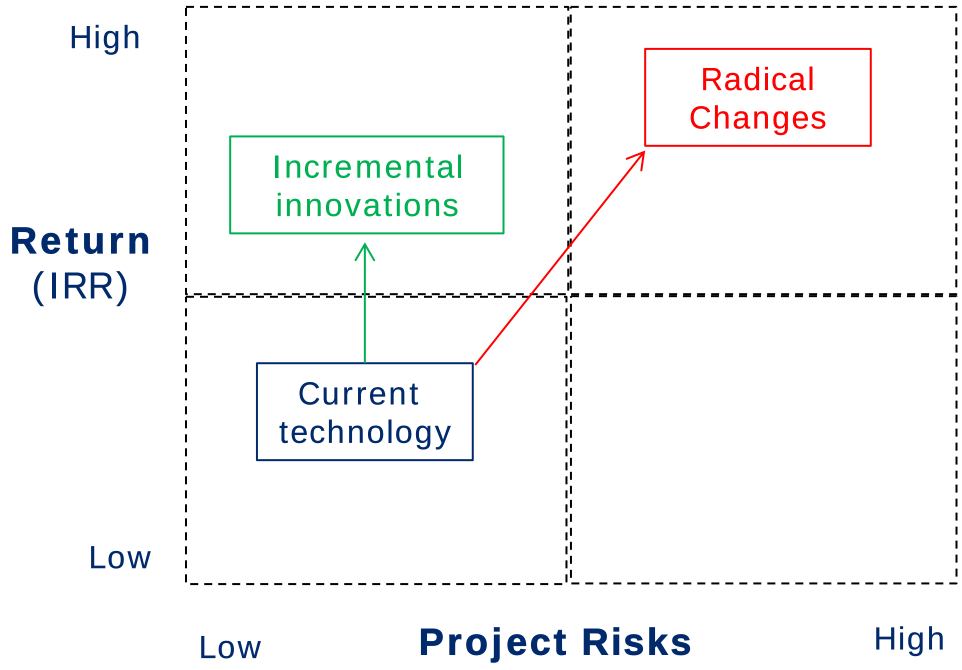
R&D activity			Commercial benefit
Numerical modelling of structural behaviour			Cost effective foundation concepts
Analyse ringing and springing effects			Improved XL monopiles
Wind farm layout optimisation			Higher energy yields
Improve rotor designs			Larger turbines

We rely on the excellent research that many organisations are doing to get innovations to market

We need innovation to improve returns

And we need to understand and mitigate risk

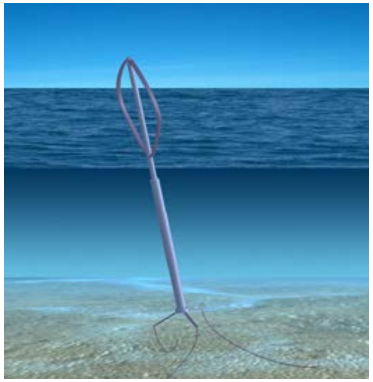
Risk-Return Ratio in the Near Future



Often innovations are **incremental changes** to trusted ideas

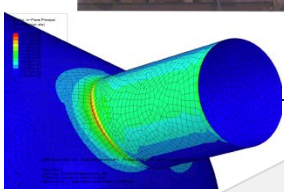
Source:Vestas V164

Occasionally innovation leads to **radical changes**



Source: Risoe DTU *DeepWind, Vertical-axis turbine combined with rotating and floating substructure*

Evaluating Technology on its way to the market?



TRL - 7
Field Proven
(Production system field proven)

TRL - 6
System Installed
(Production system Installed and tested)

TRL - 5
System Tested
(Production system interface tested)

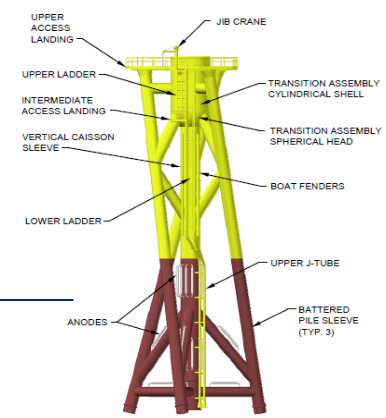
TRL - 4
Environment Tested
(Pre-production system environment tested)

TRL - 3
Prototype Tested
(System function and reliability tested)

TRL - 2
Validated Concept
(Experimental proof of concept using physical model tests)

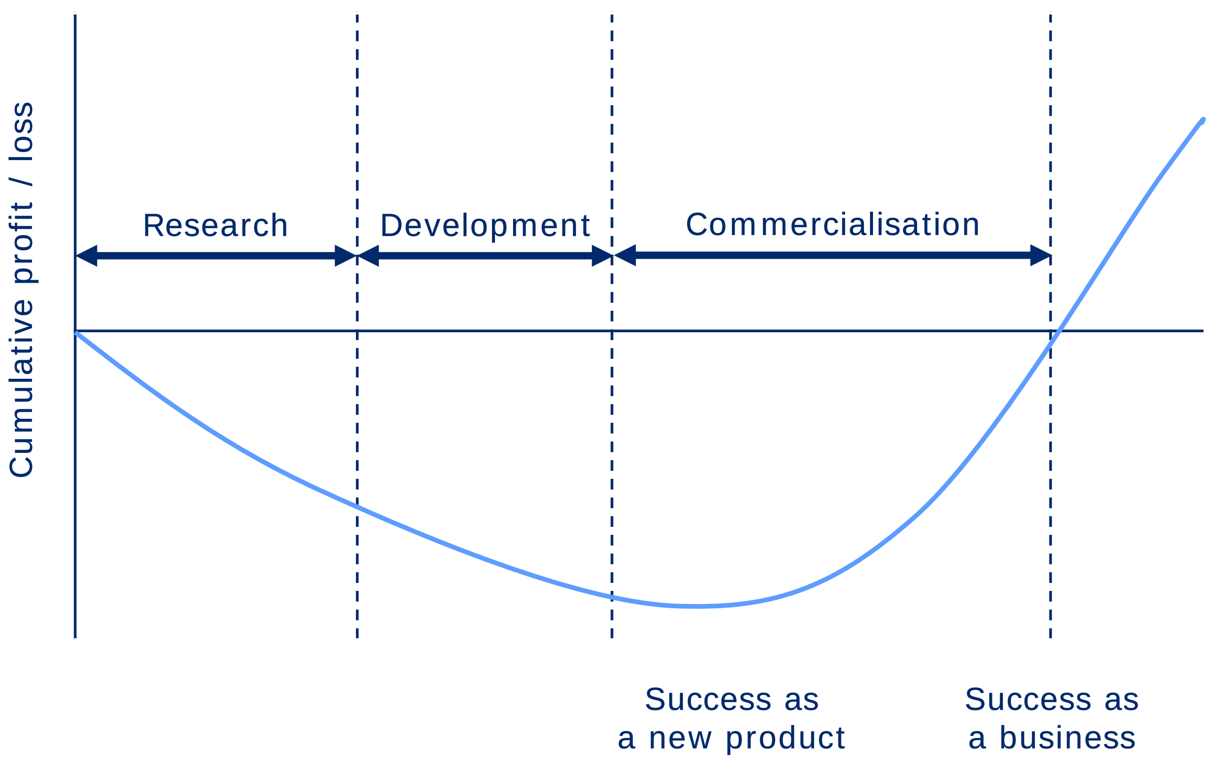
TRL - 1
Proven Concept
(Proof of concept as a paper study or R&D experiments)

TRL - 0
Unproven Concept
(Basic R&D, paper concept)



A challenging road from basic research to commercial product

How do innovations reach the market?



- From basic research to a commercial product is challenging process.
- Often a ‘funding gap’ exists between basic research and commercialization of a new product.
- This ‘valley of death’ is especially challenging in offshore wind for components that are high capex and which have a very large consequence if something goes wrong (ie, foundations or turbines).

Getting innovation into commercial projects is tough

Commercial project developers have a lot to worry about

Will my jack-up barge arrive in time?

Is my transition piece going to slip?

Can I avoid damaging my cables?

Are my turbines going to be reliable?

Will my subcontractors stay in business?

What will the weather be like?

Can you try a new foundation please?

Source: Sculpture of Atlas, Praza do Toural, Santiago de Compostela, Luis Miguel Bugallo Sánchez 2005

CARBON TRUST

How do we make innovations attractive to the market?

- **Developers must be confident new technologies are sufficiently proven and de-risked before deploying them in commercial projects**
- **Scaled testing, onshore or offshore demonstration is often required**
- **Technology needs to demonstrate clear advantages such as cost reduction**
- **Any outstanding risks must be well understood**
- **Industry collaboration can help to accelerate the derisking, demonstration and acceptance of new technologies**
  - Sharing costs, risks
  - Learning from each other
  - Pooling sites and resources

Offshore Wind Accelerator

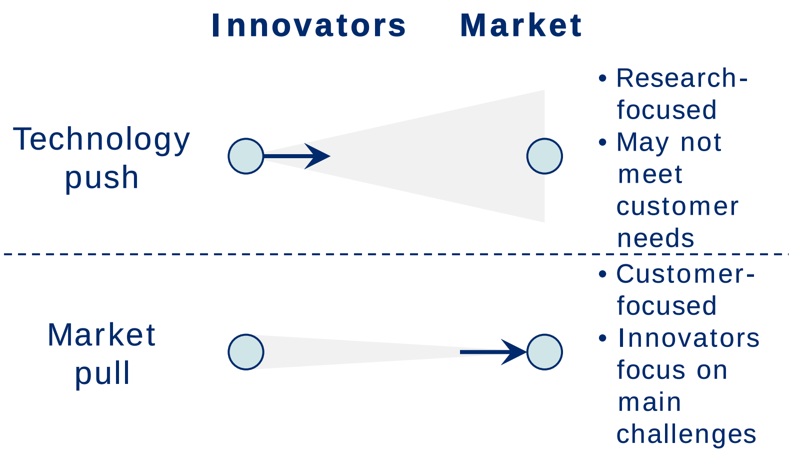
Objective: Reduce cost of energy by 10% in time for Round 3

77% (36GW) of licensed capacity in UK waters

- **Joint industry project involving 9 developers + Carbon Trust**
- **Only developers are members**
  - Aligned interests, commercially-focused
  - International outlook for best ideas
- **£45-60m programme**
  - 2/3 industry, 1/3 public (DECC)
- **Two types of project**
  - Common R&D – concept development and knowledge building
  - Discretionary Projects – demonstrations
- **Value to members**
  - New lower-cost technologies, ready to use
  - Insights into best technologies for Round 3
  - Funding for demo projects
- **Set up 2009, runs to 2016**

OWA is an example of market-pull innovation

Two approaches to innovation



UK offshore wind R&D customer-driven

Offshore Wind Accelerator

Source: Carbon Trust 2011

We need international collaboration

CARBON TRUST

OWA works with organisations around the North Sea

UK

- babcock
- TAG
- ATKINS
- J P KENNY
- FRAZER-NASH CONSULTANCY
- LOC Marine & Engineering Consultants
- ATKINS
- North Sea Logistics – Keeping the turbines turning
- FAB
- tnei
- GBF Gifford BMT Freyssinet Gravity Base Foundations
- University of Strathclyde Glasgow
- DIVEX
- HOULDER Turbine Access System
- BMT Nigel Gee
- South Boats
- SSE Renewables
- SCOTTISHPOWER RENEWABLES
- MAINSTREAM RENEWABLE POWER

Netherland

- Ballast Nedam
- GeoSea
- HEEREMA
- SPT Offshore
- Grontmij

Norway

- Statkraft
- Nexans
- Statoil

Denmark

- DONG energy
- DTU
- Knud E. Hansen A/S
- A2SEA
- Universal Foundation

Germany

- Schneider Electric
- e.on
- GL Garrad Hassan
- RWE The energy to lead
- Bilfinger Berger Civil

Five research areas

Focusing on everything but the turbine, representing 70% of LCOE

Cost of energy

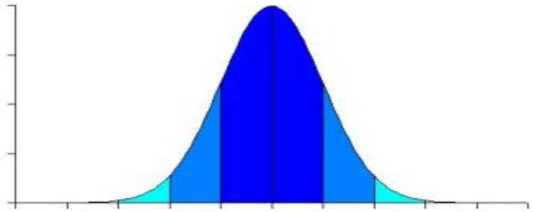
Foundations

Access systems

Electrical systems

Cable installation

Cost of finance



Wake effects

Wake Effects - The scope

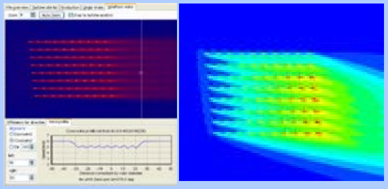
Vision to increase energy yield and reduce financing costs by improving the accuracy of wake effects models

Benchmarking of wake models
To ensure we improve the right wake models

- Benchmarking studies

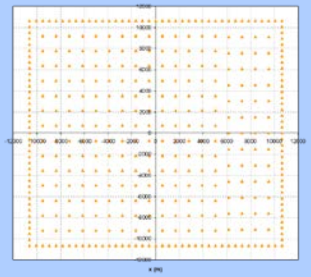
Optimisation studies
To develop better tools for offshore wind

Wake model development



- Validation and development of DTU's Fuga and ANSYS's Wind modeller
- Larger rotors
- Meso-scale modelling

Layout optimisation



- Layout optimisation tools
- Fatigue loads in array layout tool

Validation and bankability
To increase confidence in models and technology

Measurement Campaign

- Measurement campaign to capture detailed wakes data
- Array efficiency predictors
- Model validation
- Journal paper

Floating LIDAR

- FLIDAR trial
- Babcock trial
- Roadmap to commercialisation
- IEA Annex 32

Wakes measurement campaign has started at Rødsand 2

This will provide future valuation data to improve and validate wakes models

Source: Koppelius 2011, E.ON 2013

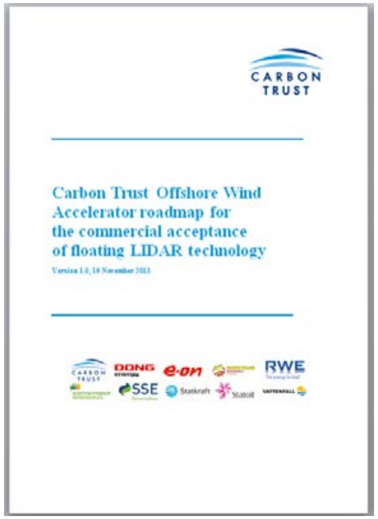
Six LIDAR units installed in 2Q2013

- 2 x long-range LIDAR to measure wake effects throughout farm
- 4 x nacelle-mounted LIDARs to record inflow and wakes at specific WTGs
- Plan to collect a year of data

Floating LIDAR

Reducing upfront investment cost

Commercialisation roadmap


CARBON TRUST

Carbon Trust Offshore Wind Accelerator roadmap for the commercial acceptance of floating LIDAR technology

- OWA Roadmap published Nov 2013 describing 3 stages required to reach bankability
- Stages measured in terms of KPIs (accuracy and availability) suppliers must demonstrate
- Industry consultation before publication (incl GLGH, ECN, DNV, Mott MacDonald)
- Will input to IEA Annex 32

OWA Validation Campaign

Objective

– To make Floating LIDAR a bankable alternative to conventional met masts

Approach

– Validation designed according to Roadmap KPI

– Gwynt Y Môr hosted provided IEC compliant met mast data

Results

– 3E's FLIDAR
  – Successful validation completed
  – New buoy design based on lessons learnt has been deployed by MRP at Narec Jan 2014

– Babcock – unit successfully deployed and is underway

Scope

FLIDAR

Babcock

Foundations - The scope

Focus on benchmarking, de-risking and optimisation

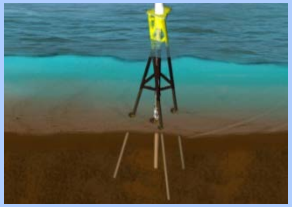
Benchmarking of Foundation Structures

To ensure we commercialise the right concepts

- Gravity base and steel structure benchmarking
- Sensitivity to larger rotor study
- Lifted versus floating GBS

De-risking of OWA concepts

To increase confidence in the concepts



- Further optimisation

- Dynamic and cyclic load studies
- Tank testing
- Installation trials
- Met mast demo

- Tank testing
- Design improvements

- Numerical modelling

General optimisation projects

To optimise fabrication and installation processes

- Serial fabrication study
- Installation optimisation study
- Maximising lifetime asset integrity
- VIBRO project
- PISA project

Two Universal Foundations installed at Dogger Bank

February and September 2013, 150km offshore, 25m depth

Benefits

– Simple fabrication
– Few marine operations
– Fred. Olsen end-to-end EPC offer
– **Significant cost reduction potential**

Image: Forewind, 2013

New JIP to improve design standards for XL Monopiles

Pile-**S**oil **A**nalysis: PISA

PISA

Aim: improve monopile design standards

Benefit: Monopiles can be used in deeper water with larger turbines

- Also improves jackets

Led by DONG Energy as an OWA Discretionary Project

Image: Cuxclipper, 2012

Access Systems - The scope

Focus on commercialising new vessel and access system technology

Identifying and benchmarking new vessel and access system technology

To fill the technology gap and ensure we commercialise the right concepts

- Access system technology review
- O&M strategy evaluation
- Design competition for new vessel and access system technology
- Regulatory review
- Development of trail procedures
- Undertaking vessel and access system sea trials

De-risking of new concepts

To increase confidence in the concepts

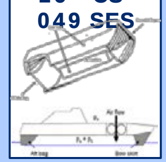
Vessels

10 - CS-322 SolidSea Transfer


11 - CS-259 Pivoting

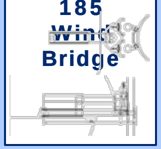

12 - CS-109 Nauti-Craft


13 - CS-415


16 - CS-049 SES


19 - CS-226


Transfer systems

01 - CS-185 Wind Bridge


02- CS-134 Auto Brow


03 - CS-


04 - CS-193 TAS2 -


Launch and recovery systems

09 - CS-146


15 - CS-062 FOB


20 - CS-


- De-risking new vessel and transfer system concepts
- Proof of concept through numerical modelling and tank testing
- Support innovators with design and tank testing
- Support innovators to build prototypes
- Support match-making with investors to ensure take-up by the supply chain

First of six Fjellstrand WindServers is now in the water

CARBON TRUST

Advantage

- Fast and efficient
- Stability in station-keeping

Source: Fjellstrand 2013

NautiCraft has just built an 8m prototype

Advantage

- Fast, comfortable
- Hydraulic connections system compensates heave

Warp mode

Pitch mode

Roll mode

Source: NautiCraft, 2013

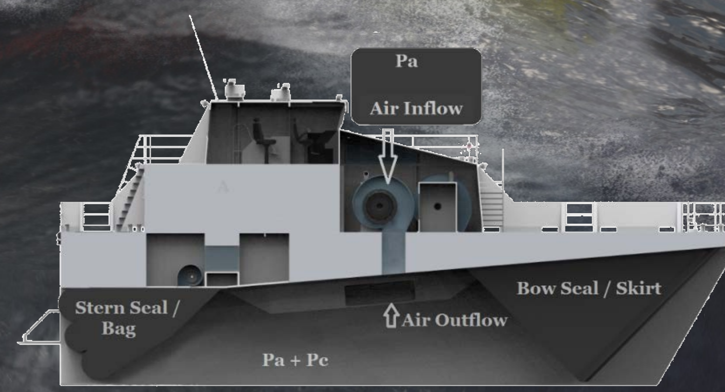
Umoe Mandal's Wave Craft

Successfully tank tested

CARBON TRUST

Advantage

- Speed
- Air cushion compensates motions



Source: Umoe Mandal 2013

Electrical Systems - The scope

Significant focus on higher voltage arrays

Technology review
To ensure we focus on the opportunities that promise most cost reduction

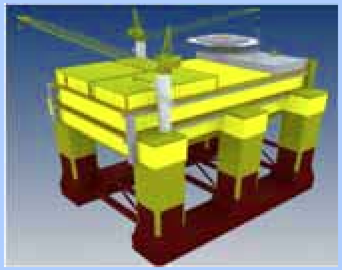
- Technology evaluation

Feasibility and optimisation studies
To increase confidence in the concepts

66KV

- Higher voltage engineering design study
- 66kV component acceleration
- 66kV cable qualification

HVDC



- HVDC technology review
- Supplier engagement
- HVDC optimisation study

AC and DC

- DC array feasibility study
- AC optimisation study

Why 66kV?

33kV

5MW Turbines
200 Turbines
1000MW capacity

3 Substation
Radial configuration

66kV

5MW Turbines
200 Turbines
1000MW capacity

2 Substation
Ring configuration

Changes in NPV compared to a 33 kV Radial Base Case

- Improvement in NPV is driven by reduced lost revenue due to increased availability (i.e. the ring design).
- The reduction in the number of substation and associated equipment is benefiting
- Some cost penalty in terms of wind turbine equipment – i.e. transformers and switchgear

Note: 0.015 failures/km/year was assumes

Cable Installation - The scope

Focus on improving cable installation techniques

Technology review

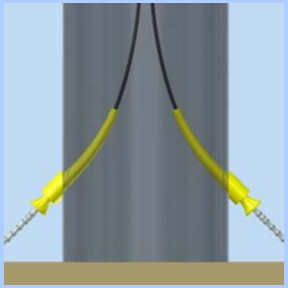
To ensure we focus on the opportunities that promise most cost reduction.

- Technology evaluation

Feasibility and optimisation studies

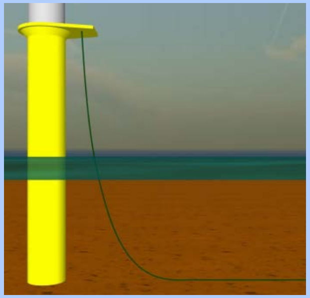
To increase confidence in the technology

Cable entry systems



- Technology review

Free hanging cables



- Feasibility study for free hanging cables

Cable burial

- Cable burial methodology and risk mitigation study

Cable installation

Vision: Reduce cable failure rates and installation costs

J-tubeless, free-hanging cables: cables would be hung from transition piece, rather than pulled through the foundation

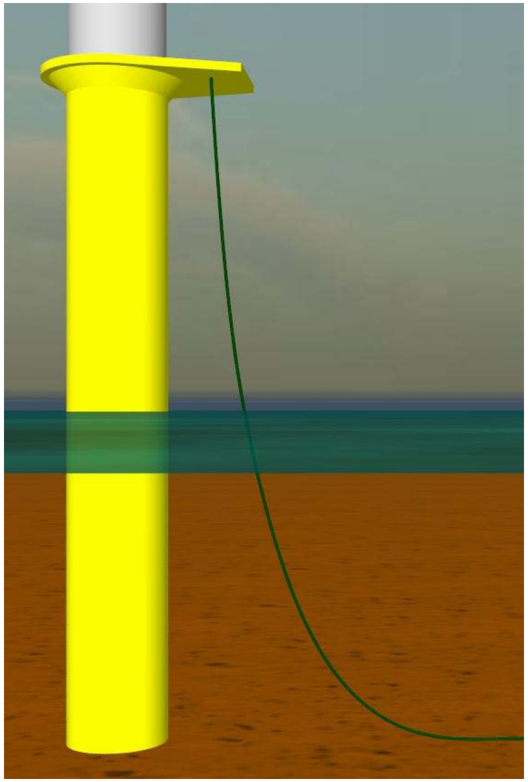


Image: Orcaflex 2013

Benefits to dynamic cables

- No J-tubes
- No divers
- No cable pull, leading to faster installation

Lower costs

Fewer risks

Conclusions

- Offshore wind costs need to come down from ~£150/MWh to ~£100/MWh by 2020
- Innovation has the potential to deliver three-quarters of this
- Research is critical to achieve cost reduction but commercialisation is challenging
- The industry is international, and we need to work together to get the best ideas – we won’t find the answers alone
- OWA, EERA and TPWind are good examples of collaborative R&D in offshore wind
- We need industry to pull the innovations to market.