Lesson Learned from European development of offshore wind and ocean renewables

5th November 2015

Our mission is to accelerate the move to a sustainable, low carbon economy

CARBON TRUST

- Created in 2001 by the UK government; now a fully independent private company

- We are an independent, expert partner of leading organisations internationally
  - We help develop and deploy low carbon technologies and solutions, from energy efficiency to renewable power
  - We advise businesses, governments and the public sector
  - We measure and certify environmental footprints

- Team of 180 experts including scientists, entrepreneurs, financiers, consultants, policy specialists, and project managers

- Offices in the UK, Beijing and Mexico. Particularly active in the EU, Japan, South Korea, China, South Africa, Mexico and Brazil

Our expertise is built on deep experience initially in the UK, but now across the EU and Worldwide

In the UK we have worked with:

75%	70%	90%	50%
FTSE 100 companies	Local Authorities	Higher Education Institutions	NHS Trusts

and undertaken:

35,000
on-site surveys

50,000
advice line calls per annum

to deliver:

£1.6bn
spend on energy efficient and renewable energy equipment

£5bn
energy waste avoided

Our innovation activities uniquely combine technical, commercial and public sector expertise in energy and resource efficiency

Carbon Trust Innovation

Innovators

- Run an incubator
- Create start-ups
- Make direct investments

Corporates

- Support strategy development and execution

Industry

- Run joint industry projects with corporates and universities to solve technical challenges

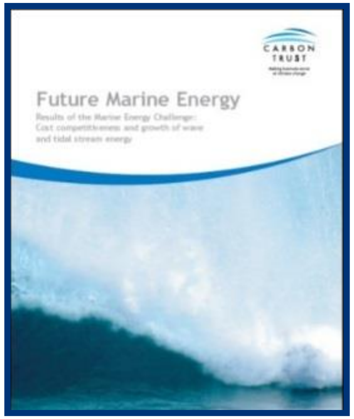
Government

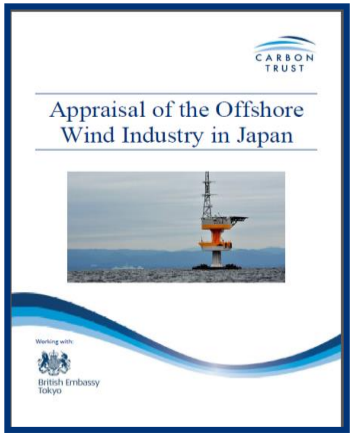
- Design and implement innovation policy
- Run tech development and demonstration programmes

We have supported government and industry to accelerate offshore renewables since 2003

- Delivered £50m (¥9bn) of marine energy innovation
  - Roadmap in 2003 to accelerate industry development
  - Technology Innovation Needs Assessment (TINA) in 2012 and 2015 to quantify value of innovation for UK
  - Founding funder of EMEC testing centre
  - Management of innovation investment programmes

- Several offshore wind government reports, plus leading the £88m (¥16bn) Offshore Wind Accelerator (OWA)
  - Government-funded roadmap in 2008
  - TINAs in 2012 and 2015
  - Design, set-up and delivery of OWA, a joint industry innovation programme focused on cost reduction





Offshore Wind

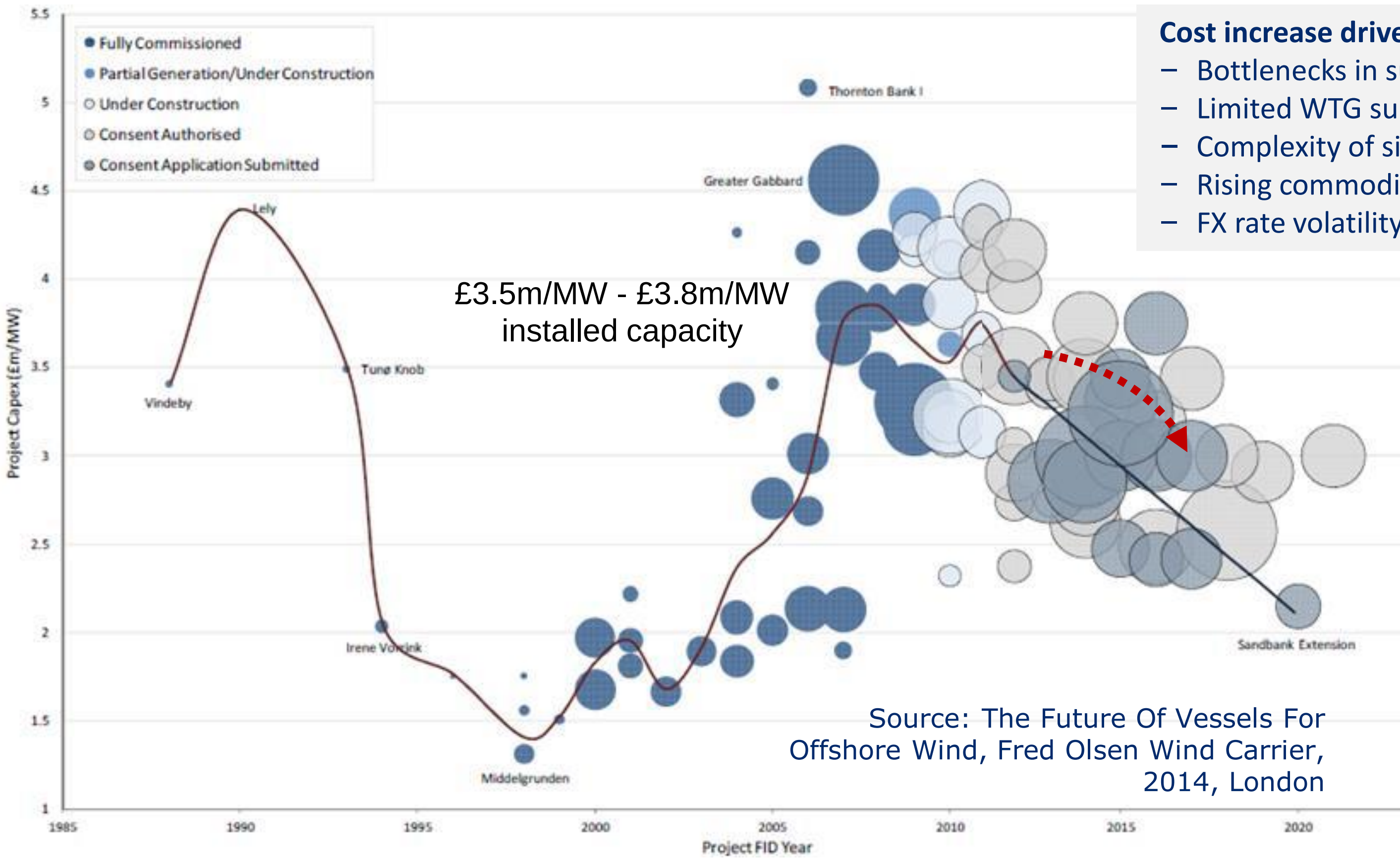
Situation analysis - Offshore Wind is still a young industry

- **Offshore wind is a young industry, near the start of the learning curve**
  - 22 years old vs 75 for gas, 115 for coal
  - ~10 GW installed vs 2,500 GW gas, 2,400 GW coal
  - Significant growth potential if costs come down
- **In the EU there is pressure on industry to bring down costs**
  - In the UK, costs need to come down from ~£120/MWh (22 yen/kWh) to ~£100/MWh by 2020 (19 yen/kWh) for fixed foundations
- **Plenty of scope for further cost reduction**
  - Mainly from increased deployment and innovation…
  - …and also from supply chain and finance
- **If we can get innovations to market quickly, the industry can deliver significant cost reduction**

1 GBP = 187 JPY

Costs in Europe were increasing, but are now falling fast

Cost increase drivers
- Bottlenecks in supply chain
- Limited WTG suppliers
- Complexity of sites, distance, depth
- Rising commodity prices
- FX rate volatility

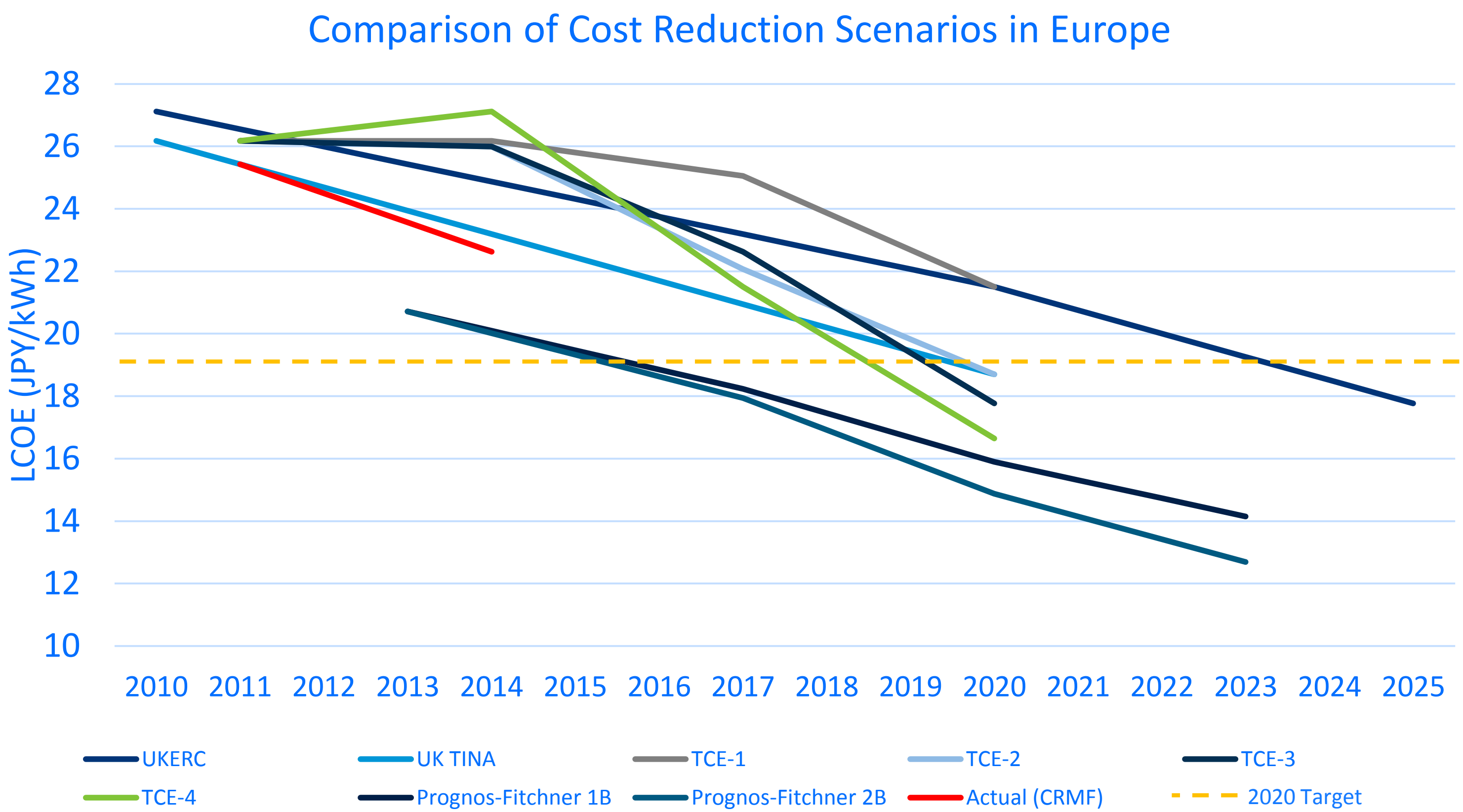


Source: The Future Of Vessels For Offshore Wind, Fred Olsen Wind Carrier, 2014, London

But site conditions are becoming more challenging…

Offshore wind is on track to reach 2020 cost targets

- Range of studies confirm significant cost reduction potential of 25-40%
- Actual data is ahead of target (11% reduction achieved from 2011-2014)



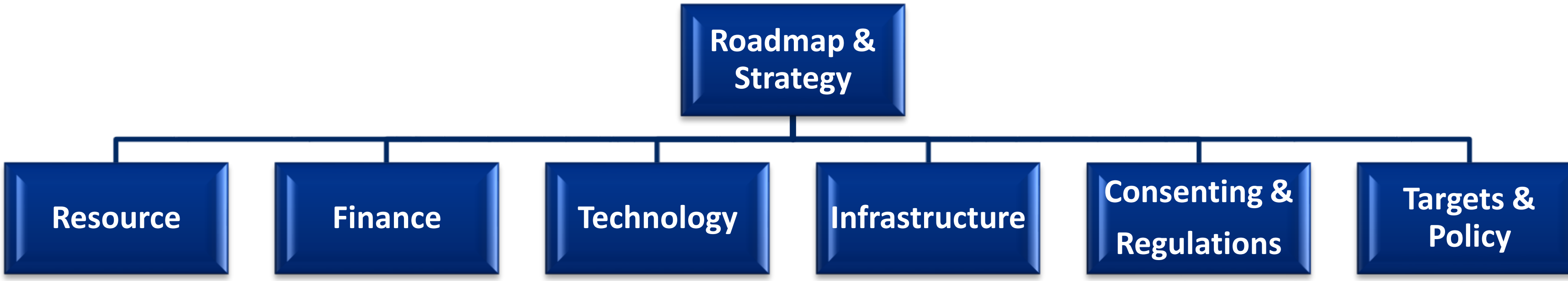
Notes: [1] Phasing of cost reduction between data points assumed to be linear. [2] Prognos-Fitchner study focusses on German market, where grid connection is paid for by the government, hence the lower LCOE compared to UK studies where grid connection is paid for by the developer.

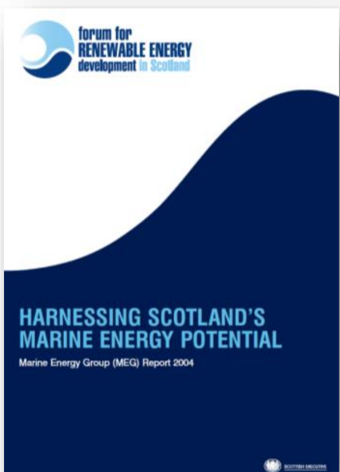
Sources: UKERC (2010); Crown Estate (2012); Prognos-Fitchner (2014); ORE Catapult (2015); Carbon Trust analysis

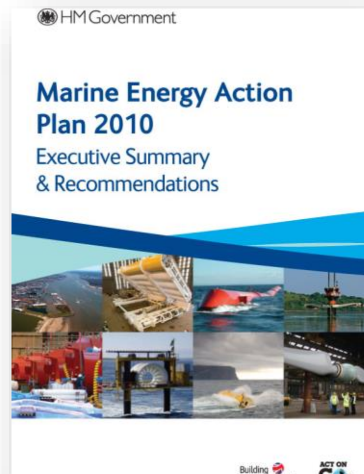
1 GBP = 187 JPY

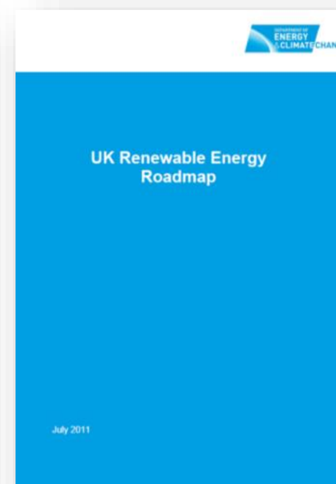
Europe's strategic approach has been underpinned by roadmaps

Typical roadmap content:









The roadmaps are used to drive policy and to create confidence in the market

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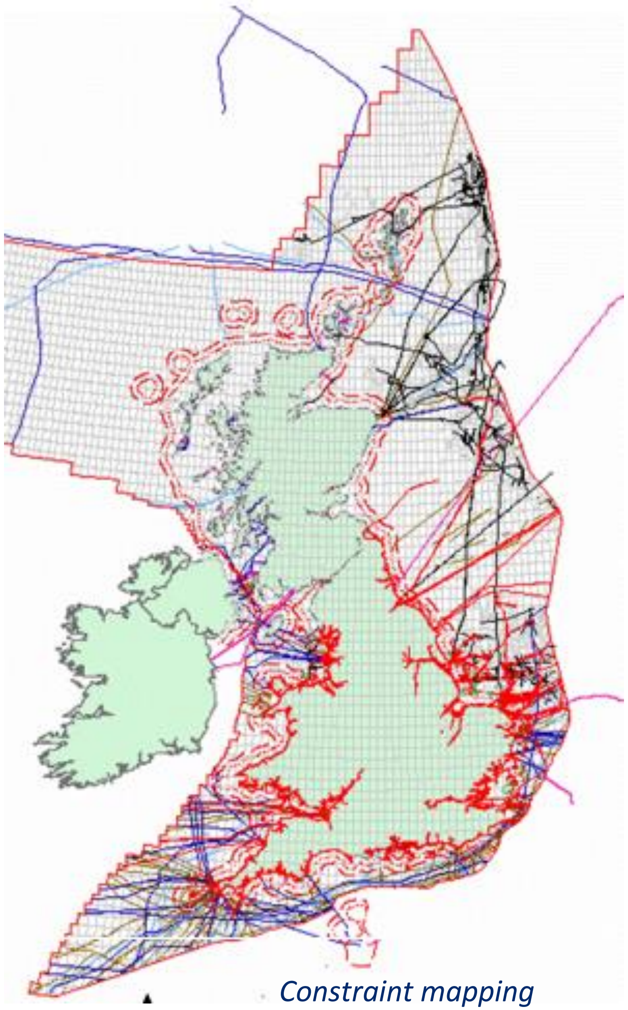
- Industry needs to be confident in the market before investing
- Positive government policy targets and a clear project pipeline boosts investment
- The right balance is required between long term confidence and an attractive incentive system
- Confidence and incentives need to be revisited occasionally, but without creating uncertainty

Leasing zones, identified by spatial planning tools, proved to be an effective way of providing market certainty

- In the UK, the Crown Estate owns the right to the seabed and has held several leasing rounds, based on its Marine Spatial Planning System (MARS)
- MARS is able to map a series of physical and human constraints
  - E.g. Wind resource; water depth; seabed geology; shipping routes; conservation zones; oil & gas activities
- Tool can then be used to inform and optimise site selection for offshore wind development zones
- Developers can select specific sites within the development zone
- Negotiating pre-approval from relevant stakeholders is critical and can speed up consenting for designated sites, reducing time, cost, and risk for developers



Constraint mapping

Developer risk was reduced by government obtaining consent prior to tender

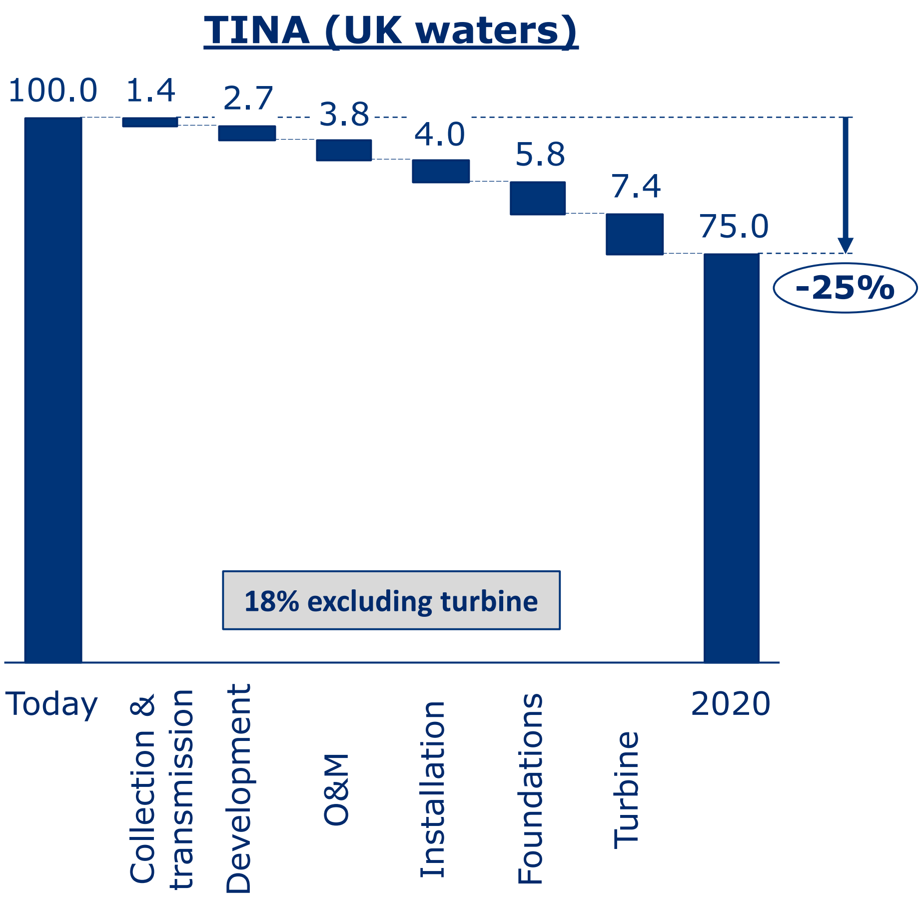
- Obtaining consent can be time-intensive and costly
- Streamlining the consenting process can reduce risk for developers
- One-stop-shop – bundle permits and licenses into a single authorisation process, administered by a centralised body
- Several countries secure consent before tendering the rights to the wind farm (Denmark, Netherlands)
  - Government conducts EIA and attains consent for site before tendering
    - Removes high cost to developers before they can even apply for a subsidy

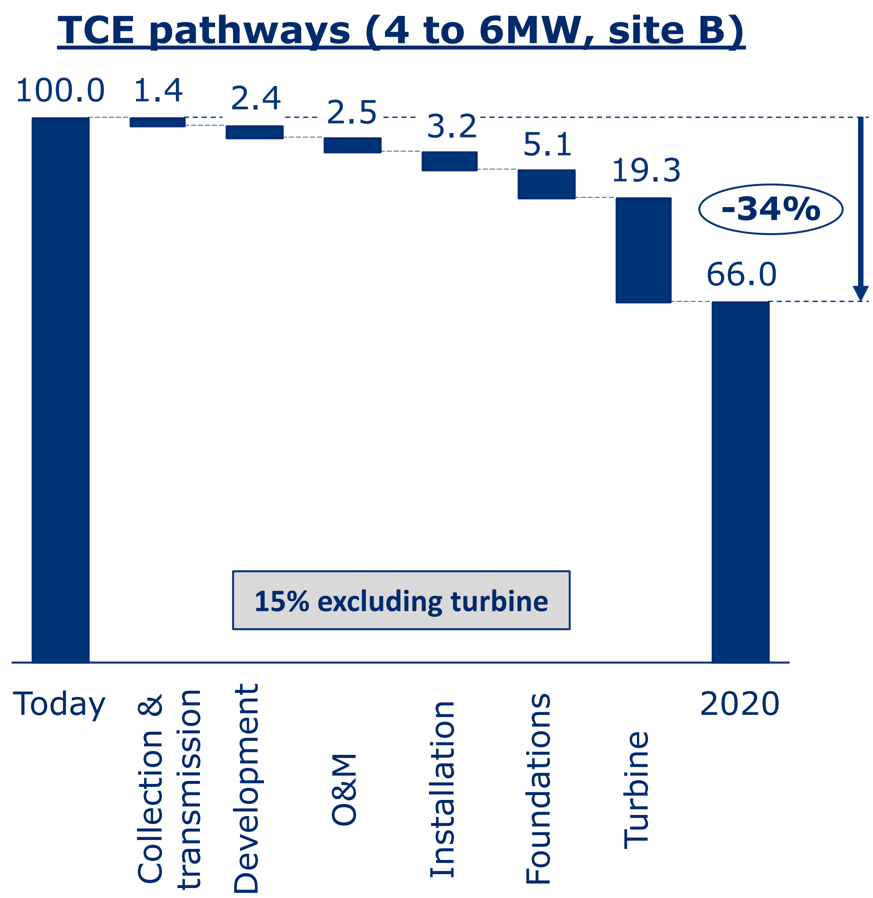
Bird Collision Avoidance Study

Acoustic Deterrent Device Study

- Research projects can increase confidence in the true environmental impact of offshore wind farms
  - E.g. ORJIP – joint industry project to reduce consenting risk

Innovation could deliver 25% cost reduction by 2020



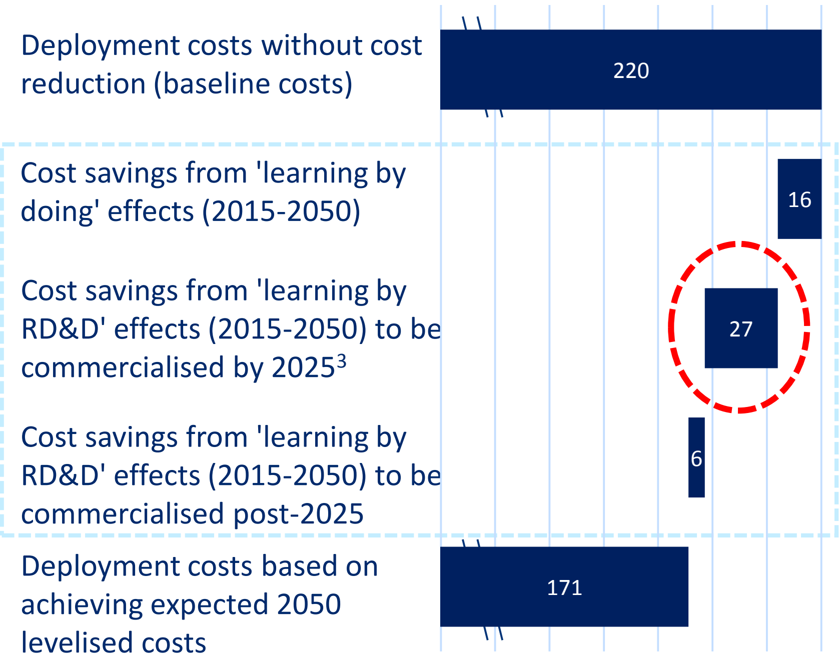


Note: TINA suggests further cost reduction is possible from turbines if there is more competition – up to ~15% LCOE reduction
Source: TINA Executive Summary 17 Jan 2012; initial TCE pathways innovation model outputs 2 Feb 2012

Public funding accelerates cost saving by overcoming key market failures

An accelerated commercialisation of innovations will increase savings, as lower cost technologies will benefit all future deployments

Cost savings estimate
2015-2050, discounted £bn, med deployment/high innovation



A number of overall market failures inhibit innovation

- The high degree of **demand uncertainty** reduces the incentive to invest in innovations.
- The aversion individual developers have to including new innovations in their wind farms due to the **increase in cost and risk**
- The **lack of incentive for any one player** in the industry to incur the costs of investing in innovations that will ultimately benefit the industry as a whole.
- The **lack of competition** in certain sectors in the supply chain reduces the need to innovate.

Significant opportunity for innovation to drive down costs

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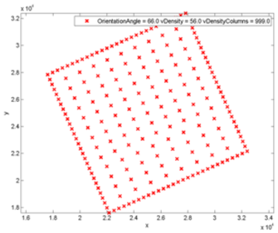
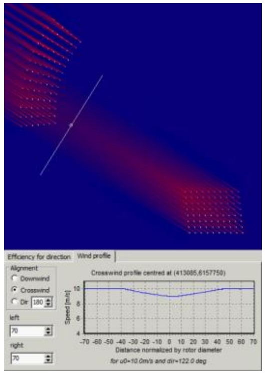
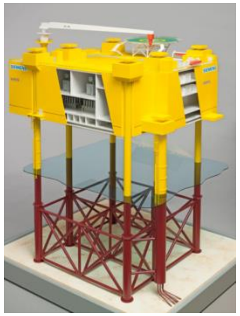
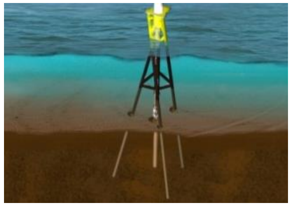
Development	Electrical	Foundations	Installation	Turbine	O&M

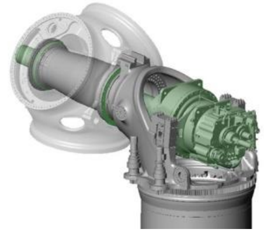
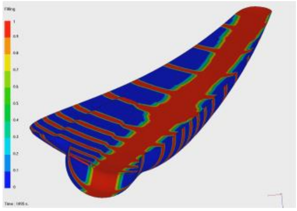













The Offshore Wind Accelerator (OWA) works with developers to reduce offshore wind costs

- Joint industry project involving 9 developers + Carbon Trust
- Only developers are members
  - Aligned interests
  - Commercially-focused
  - Preferential access to new technology
- £88m (¥16bn) programme
  - 2/3 industry, 1/3 government
- Focus on overcoming near-term technical challenges

Active in ¾ of the UK's offshore wind projects

OWA works with industry and government to bring new technologies to market

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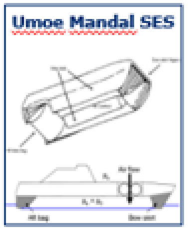
Access Systems Case Study: Umoe Mandal 'WaveCraft'

<u>Challenge:</u> Safely transferring personnel from in-field vessels to and from the wind turbines

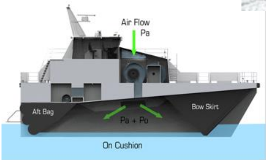


TRL - 0

2011

Un-proven Concept

Entry into OWA Access Competition (450 submissions)



TRL-1

2012

Proven Concept

De-risking process as part of the OWA Programme.

TRL-2

2013

Validated Concept

- Tank testing campaign
- Design improvements
- Active control design

TRL-3

2014

Prototype Tested

- Umoe Mandal starts building the first vessel.
- Implementation of the motion control system takes place

TRL-7

2015

Field Proven

Vessel is now operational at Borkum Riffgrund for Dong Energy. Second vessel is in fabrication.

PISA project stakeholders - an example

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CT Role:

- Set up
- Coordination
- Technical input
- Problem solving
- Mediation

Discretionary Project Steering Committee

- CARBON TRUST – Jan Matthiesen / Marc Costa Ros
- DONG energy – Morten Liingaard
- IBERDROLA – Chris Leach
- RWE – Daniel Bartminn / Emmet Donegan
- SSE – Alan Smith / Mike Rose
- Statoil – Pål Johannes Strøm
- Statkraft – Eivind Sønju
- VATTENFALL – Kasper Roed Jensen

Independent Technical Review Panel

- NTNU – Chairman: Professor Gudmund Eiksund
- DNV – Liv Hamre
- GD CONSULT – Dr Fabian Kirsch
- GL Garrad Hassan – Tim Camp
- BAM Bundesanstalt für Materialforschung und -prüfung – Professor Werner Rucker

Lead Partner

DONG energy

Project Manager:
Jesper Skov Gretlund

Technical Manager:
Alastair Muir Wood

Project Partner Technical Experts

- CARBON TRUST – Marc Costa Ros
- DONG energy – Christian Le Blanc
- IBERDROLA – Pedro Barbosa Moreira
- RWE – Volker Herwig / Emmet Donegan / Daniel Bartminn
- SSE – Alan Smith / Mike Rose
- Statoil – Pål Johannes Strøm
- Statkraft – -
- VATTENFALL – Wolfeckart Semm, Manouchehr Hassanzadeh
- ALSTOM – Miguel Lanca Coelho

Assisting Consultants

- ORDTEK – UXO Consultant
- PARSONS BRINCKERHOFF – Structural designer and SI supervision
- GCG – Advanced numerical modelling
- ATKINS – Site management

Academic Work Group

Principal Investigator: Dr Byron Byrne
Professor Guy Houlsby, Dr Harvey Burd, Dr Chris Martin, Dr Ross McAdam

Imperial College London
Professor Richard Jardine, Professor David Potts, Professor Lidija Zdravkovic, Dr David Taborda

UCD DUBLIN
Dr Ken Gavin, Dr Paul Doherty

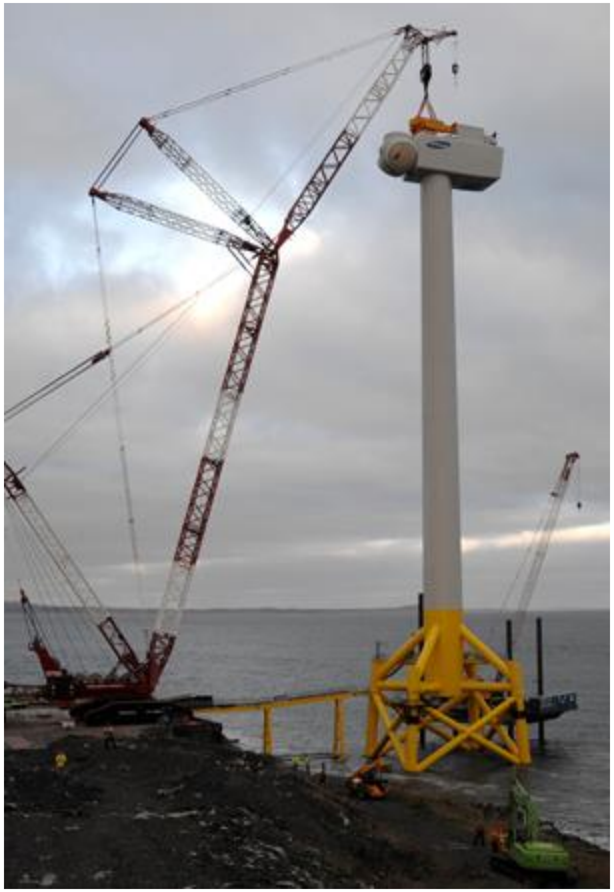
Testing Contractors

NLMK DanSteel A/S, BLADT INDUSTRIES, CONCEPT, IN SITU SITE INVESTIGATION, marmota geotechnical experts fiber-optic monitoring, DAWSON CONSTRUCTION PLANT LTD, ESG Environmental Scientifics Group, GEOLABS

Demonstrating technology was critical for reducing finance costs

- Demonstrating technology created confidence, proved interfaces and system integration, and allowed for monitoring and learning before full-scale deployment
- Most importantly, demonstrations convinced the finance and insurance sector that risks were understood and manageable

Reducing WACC from 10% to 6% can lead to LCOE reductions of ~25%



Floating Offshore Wind Can Open New Markets

- Expand market to >50m water depths
- Access <u>near-shore</u> deep water sites with strong wind resource
- Cheaper installation – assemble at port, no large vessels
- Cheaper O&M – port-side repairs
- Avoid far-shore transmission issues
- Decoupled from the seabed – amenable to standardisation and serial production

Source: Principle Power – WindFloat, Portugal

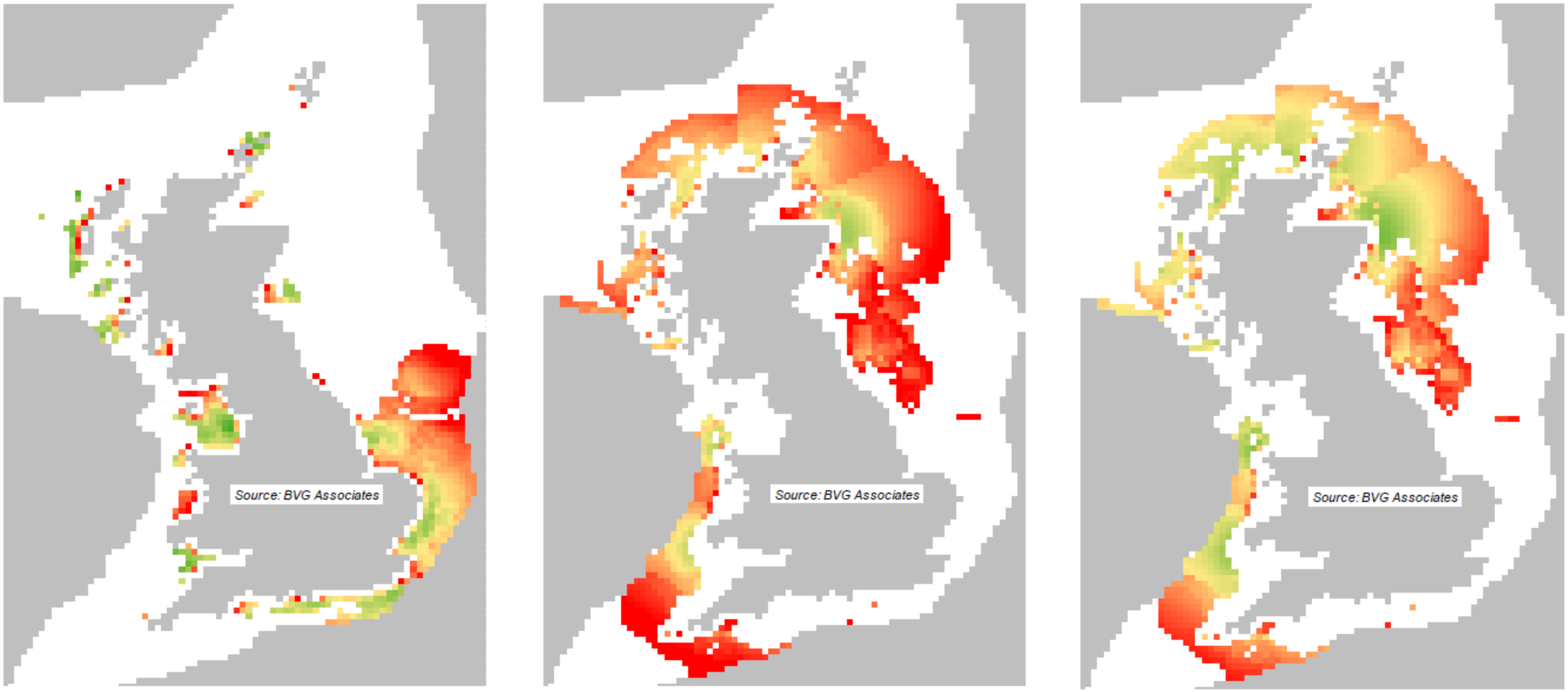
Floating wind is gaining momentum

Series of full-scale demonstrations and pre-commercial arrays in development

- Increasing turbine capacity from 2 MW to **6+MW**
- Scale of projects increasing from single prototype to pre-commercial arrays (**30-50 MW**)
- Cumulative capacity of **~240 MW by 2018-2020**
  - Commercial-scale wind farms contingent on success of these initial pilot projects

Scotland is well-suited to floating offshore wind

- Excellent site conditions:
  - Strong wind resource
  - Deep water sites, close to shore
- Leverage experience from North Sea oil & gas, plus the UK offshore wind industry
- If the UK deploys 40 GW offshore wind by 2050, 8-16 GW could come from floating



5m < water depth ≤ 50m | 50m < water depth ≤ 500m | 10MW rated turbine

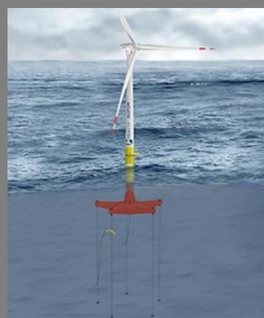
Key: Green = <£100/MWh; Yellow = £115/MWh; Red = £130-135/MWh

Source: ETI/BVG (2015)

Three projects in the pipeline up to 2018

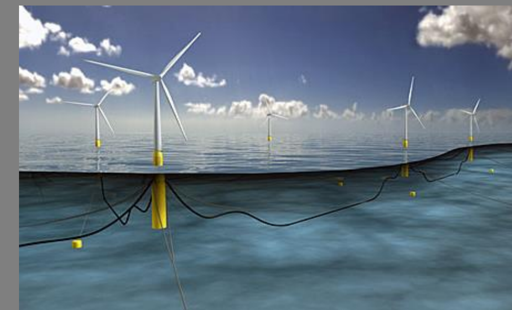
Incentivised by enhanced subsidy support from the Scottish Government

Dounreay Test Facility **30 MW**



- **Concept:** Multiple TBC – TLP?
- **Developer:** Highlands & Islands Enterprise
- **Turbine:** 6 MW x5
- **Status:** Awaiting approval for grid connection; installation planned for 2018

Hywind Pilot Park **30 MW**



- **Concept:** Hywind spar buoy (Statoil)
- **Developer:** Statoil
- **Turbine:** 6 MW x5
- **Status:** FID in September 2015; installation 2017

Kincardine Pilot **48 MW**

- **Concept:** WindFloat (Principle Power)
- **Developer:** Pilot Offshore
- **Turbine:** 6 MW x8
- **Status:** Installation planned for 2018

› Race to install projects by 2018 to qualify for enhanced ROCs (3.5)*

› Currently no successor subsidy mechanism beyond 2018

*1 ROC = ~£45/MWh; 3.5 ROC + wholesale = ~£208/MWh

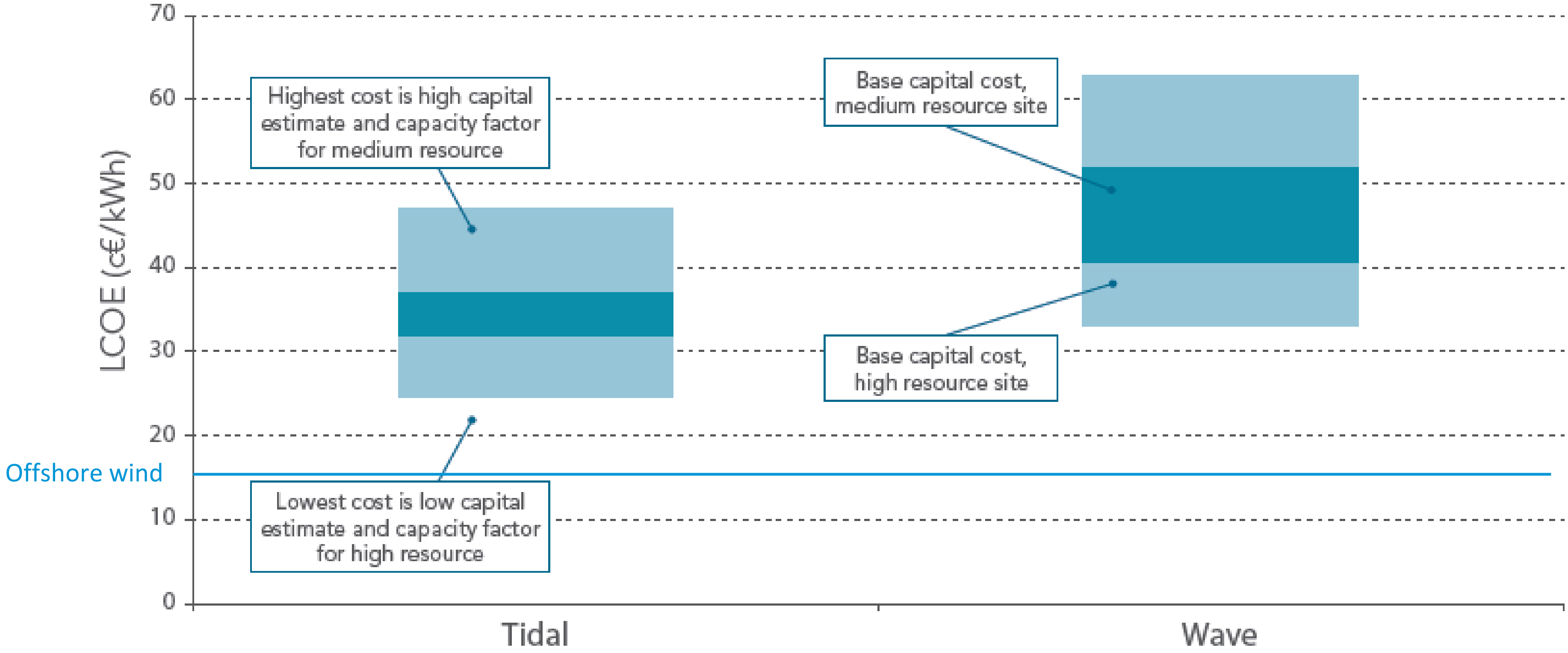
Marine Renewables

Marine Energy - Executive Summary

- Marine energy is 10-15 years behind offshore wind
  - Wave is in an R&D phase; viable technologies emerging but unproven
  - Tidal Stream energy has more proven devices, some of which are now being tested in commercial demonstration arrays

- Key factors which have enabled progress to date:
  - Strategic roadmaps to align public and private sectors
  - Sustained public RD&D support over a period of 10+ years and £150m
  - Visibility of high value revenue support schemes for generation
  - Development of key enabling infrastructure, like the EMEC test centre
  - Access to known high resource deployment locations with defined consenting and leasing arrangements
  - An active academic research community

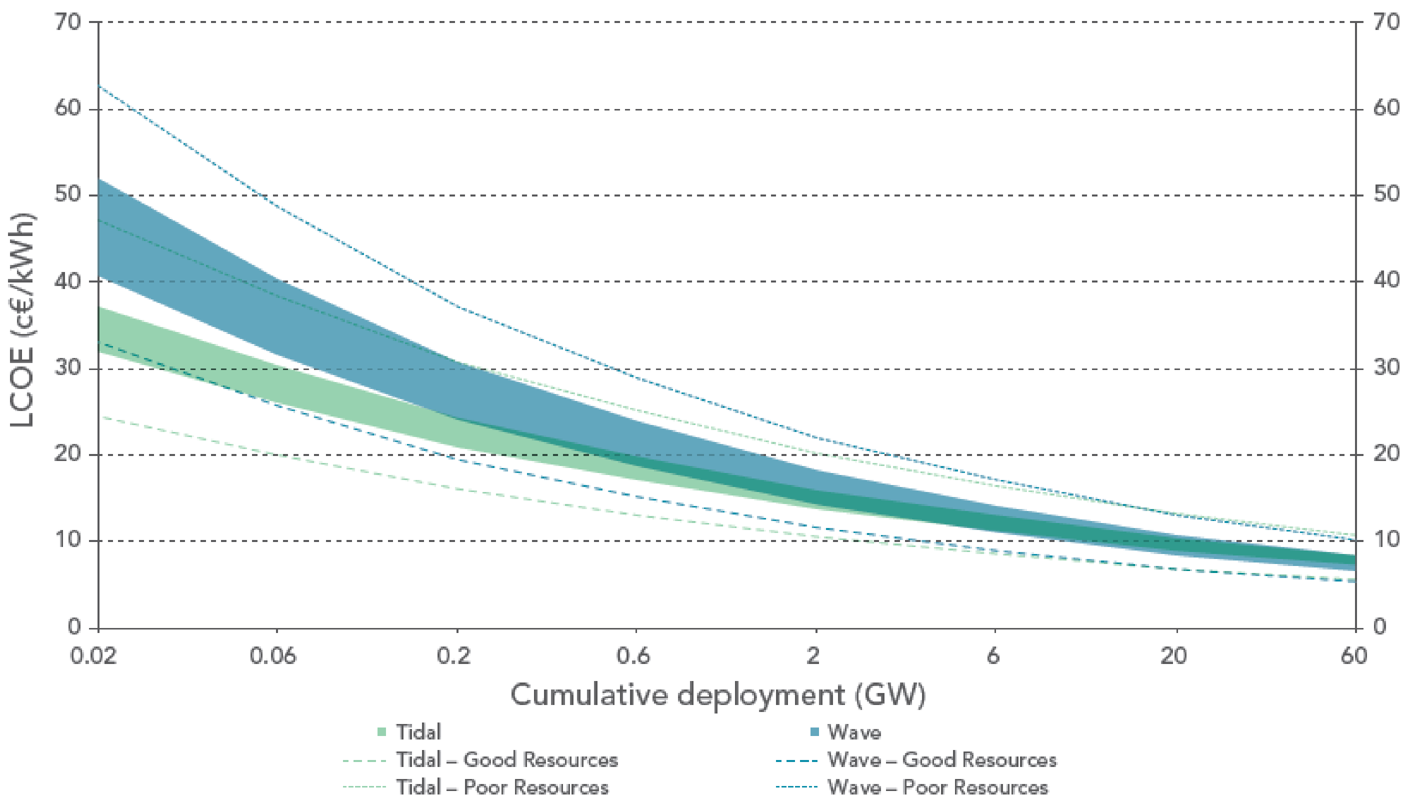
The expected costs of the first wave and tidal arrays are quite high



› Early array costs are based on data from technology developers, forecasting the costs of a 10MW array when 10MW capacity has already been installed

Wave and tidal future costs are dependent on future deployment and innovation

Figure 5 – LCOE predictions for 10MW early arrays, after 10MW already installed (SI Ocean, 2013)



- Cost reduction = Economies of Scale + Learning by Doing + Innovation

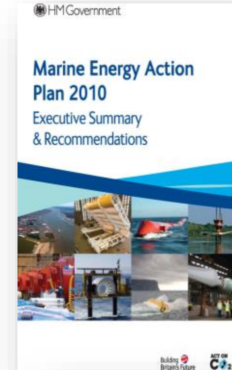
Source: SI Ocean, Feb 2014

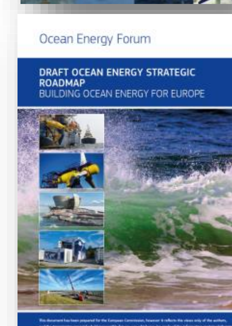
The UK and Europe set targets for marine energy although these now look optimistic

- **Marine Energy Action Plan UK (2010)**
  - 1–2 GW by 2020
  - Developed by Government with private sector input

- **European Targets (2013)**
  - 1.4 GW by 2020
  - 100 GW by 2050

- **Draft Ocean Energy Forum Roadmap (2015)**
  - 0.3 GW by 2020 wave and tidal
  - 0.9 GW by 2020 including tidal range





Wave and tidal technologies are pre-commercial

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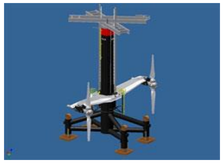
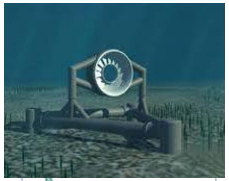
Leading Wave -> Leading Tidal ->

Concept/tank testing → Part-scale demo → Full-scale at-sea demo → First farm deployment 5-10MW → Full 'commercial'

Lots

Many






c.15 devices

MeyGen 6MW under construction, due for completion 2016, c.¥10bn

Andritz x3

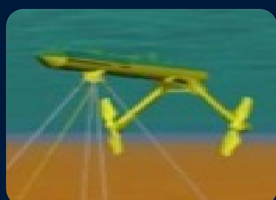
Atlantis x1

None

The first generation tidal businesses have benefitted from strong corporate backers

EXAMPLES

Marine Current Turbines
Rated Power: 1.2MW
Rated velocity: 2.4+ m/s
Corporate backer: Siemens



Scotrenewables
Rated Power: 2MW
Rated velocity: 2.5 m/s
Corporate backers: ABB, Fred Olsen

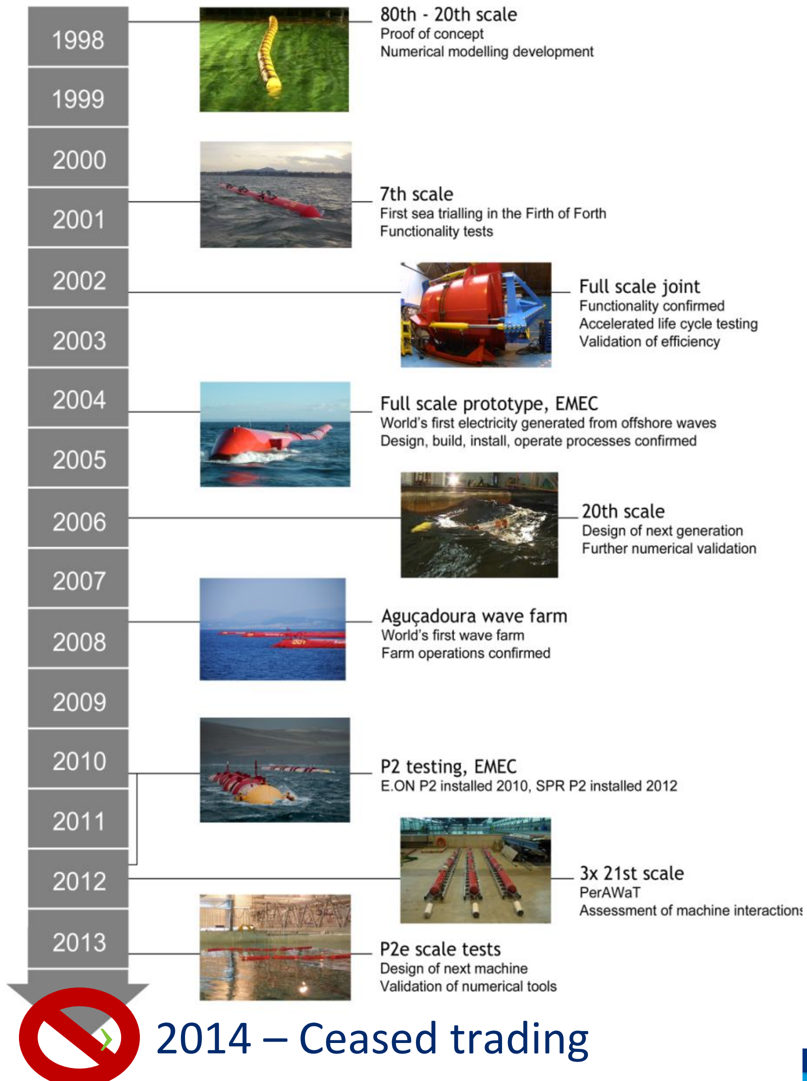
Andritz Hydro Hammerfest
Rated Power: 1MW
Rated velocity: 2.2 m/s
Corporate backer: Andritz Hydro

Open Hydro
Rated Power: 1MW
Rated velocity: 2.6 m/s
Corporate backers: Bord Gais, DCNS

The UK wave industry has been struggling

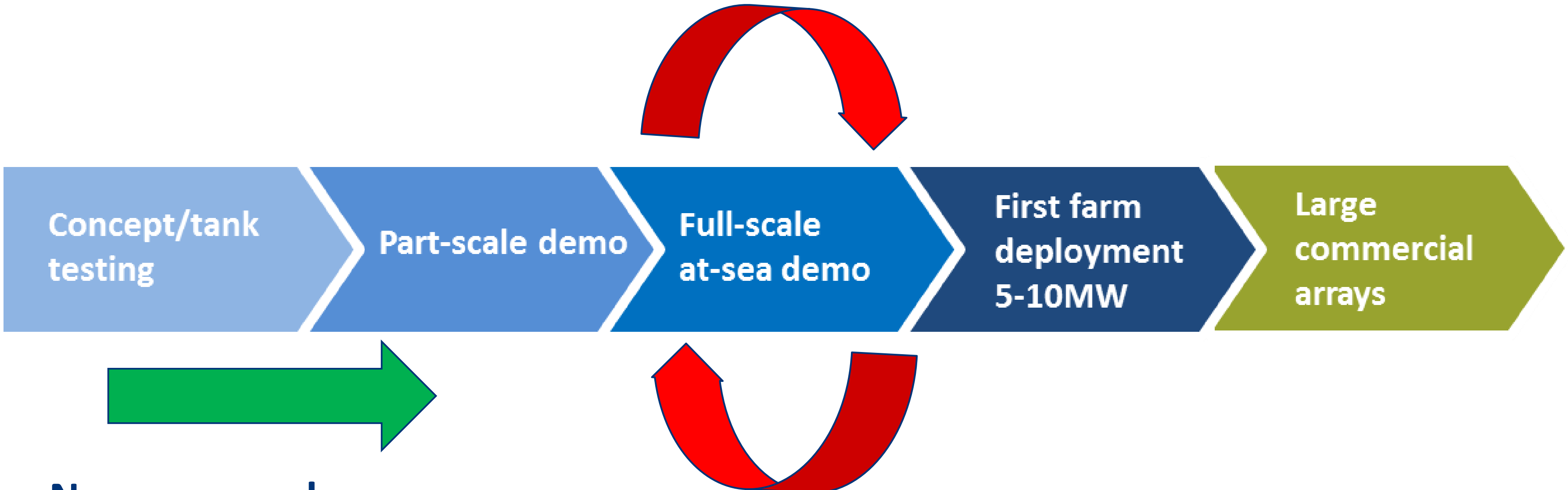
- Key lessons:
  - Large scale devices designed built, installed and generating
  - Market opportunity confirmed
- Challenges:
  - Proving performance and reliability
  - Inadequate resources relative to the task
  - Access to finance and funding
  - Lack of OEM industrial involvement
  - Lack of design convergence

Pelamis case study, after c. £70m R&D



2014 – Ceased trading

As a result, the UK wave industry has gone “back-to-basics”



New approach – back to basics stage gated R&D pathway to success

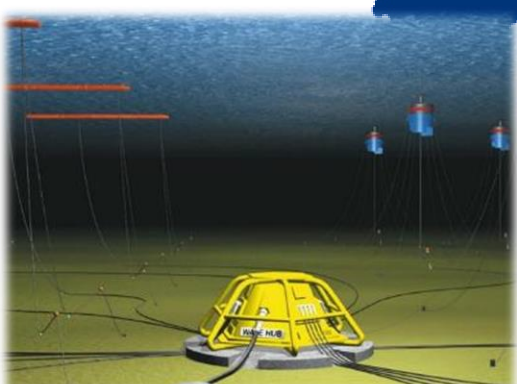
Old approach - Full scale valley of death

Testing infrastructure is crucial to industry development

Several Test tanks like FloWave

EMEC

NAREC



Wave Hub

Appropriate test centre design is critical to meet the needs of the market

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EMEC ORKNEY
THE EUROPEAN MARINE ENERGY CENTRE LTD

- Wave and tidal at sea test centre
- Small and large scale facilities
- £36m public funding and now self-sustaining
- ~12 devices under test
- Established 2003

narec

- Wind, wave and tidal test and research facility – test rigs (drive trains, turbine blades), tanks
- Small to large scale facilities
- £150m public and industry funding
- Established 2002

Wave Hub

- Wave only at-sea test centre
- Large scale facilities
- £42m public funding
- Limited devices under test
- Established 2003

Significant supply chain benefits are realised locally via marine energy development

- There are around 1,700 people working in the UK wave and tidal sectors
- This could grow to over 20,000 skilled jobs in the next decade
- Nearly £450 million spent to date in the UK supply chain

Tidal stream is particularly dependent on the success of the MeyGen project

CARBON TRUST

- First generation concept array demonstration needs to be successful
  - Sector has consolidated around the MeyGen project
  - Prove 6MWs (3 Andritz Hydro Hammerfest, 1 Lockheed Martin/Atlantis Turbine) - due to be commissioned in 2016
  - MeyGen must secure funding for Phase 2; may depend upon a period of successful operations of phase 1 but has £15m in place from EU
  - Costs need to continue to come down
  - Other developers unlikely to able to fund projects until MeyGen proven

- Continued 2nd generation development demonstration at EMEC with novel potentially step change cost reduction concepts, mainly floating

- Tidal Range developments are positive but also a potential threat to tidal stream funding and a political distraction

Wave energy is further behind and dependent on Wave Energy Scotland

- Various concepts have proven the potential, but reliability and performance leading to an affordable LCOE have still to be demonstrated
- Developers have over-promised, eroding investor confidence
- Development costs and timeframes suggest 5-10 years and £50-100m plus R&D spend is needed to prove the technology sufficiently to get the private sector re-engaged
- Initiatives like Wave Energy Scotland and the US Wave Energy Prize are taking a back-to-the-tank approach, but this is not a unanimous approach amongst funders. There needs to be consolidation of device types and emergence of winning solutions