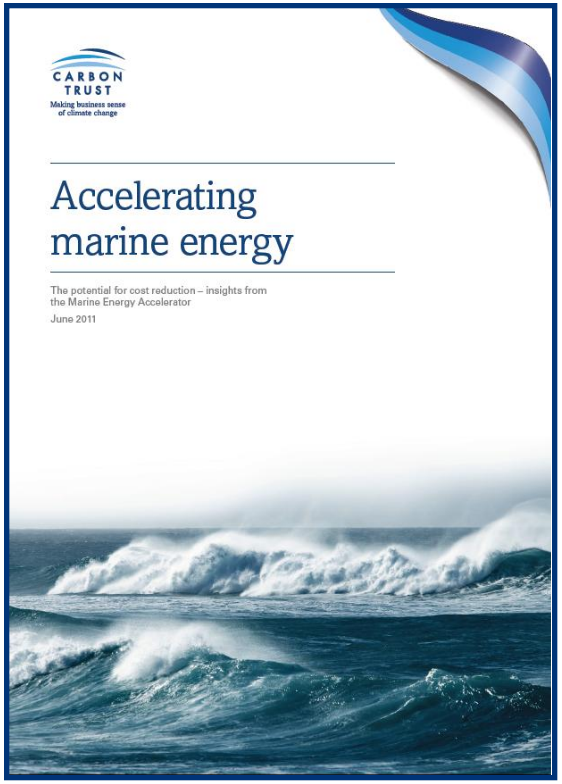
Accelerating Marine Energy

Findings from the Marine Energy Accelerator, and directions for future innovation

Stephen Wyatt, Head of Technology Acceleration

Agenda

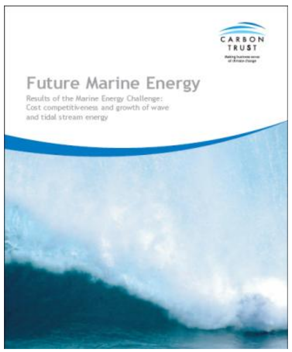


Final report of the Marine Energy Accelerator July 2011

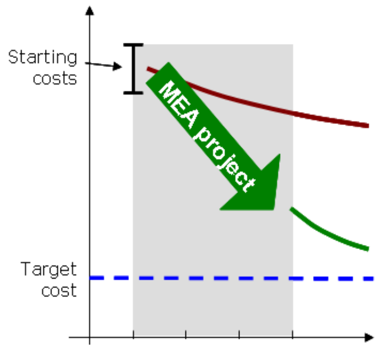
- Carbon Trust Marine Energy work
- The approach of the MEA
- Cost of marine energy
- Cost reduction routes and case studies
- What next for Marine Energy?

CT has been working in marine energy since 2003

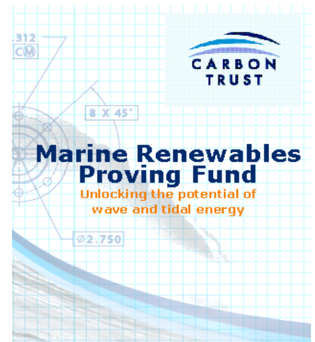
Understanding the challenge	Accelerating cost reduction	Proving the technology	Facilitating development



Marine Energy Challenge 2003-2006



Marine Energy Accelerator 2007-2010



Marine Renewables Proving Fund 2009-2011

EMEC

Founding Funder since 2005

- **CT have been working with the marine energy industry since 2003 and have invested £30m.**
- **The MEC helped CT and the industry to understand the barriers to marine energy development.**
- **Current focus is on full scale demonstration (MRPF) and cost reduction (MEA).**
- **EMEC test centre is vital to the industry, and provides cost-effective open-access infrastructure**

The MEA aimed to demonstrate and understand *cost of energy* reduction potential through targeted innovation

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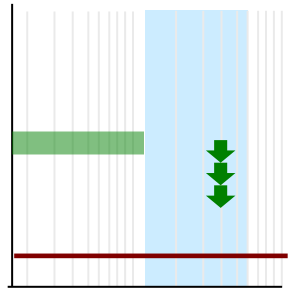
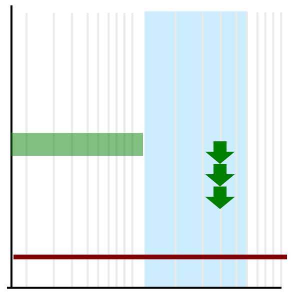
Working with *existing* device concepts to develop a set of cost reductions

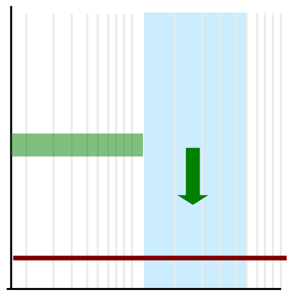


Component technology innovation in areas such as blades, structural materials, costs



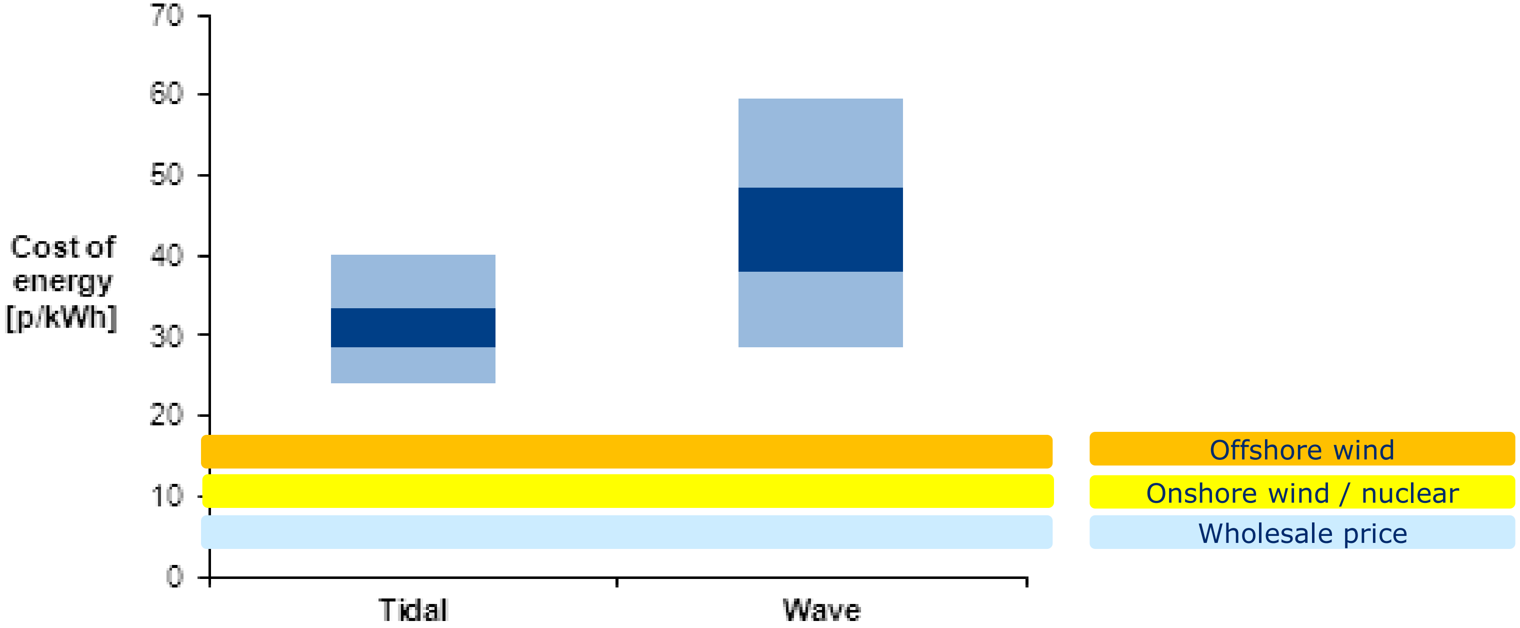
Reduction of installation, operation and maintenance costs

Working with *new* device concepts to explore the potential for a single step change in cost of energy



Development of new, concepts with the potential to provide a step change reduction in the costs of energy.

The MEA has established new benchmarks for the costs of wave and tidal energy which are based on real cost and performance data



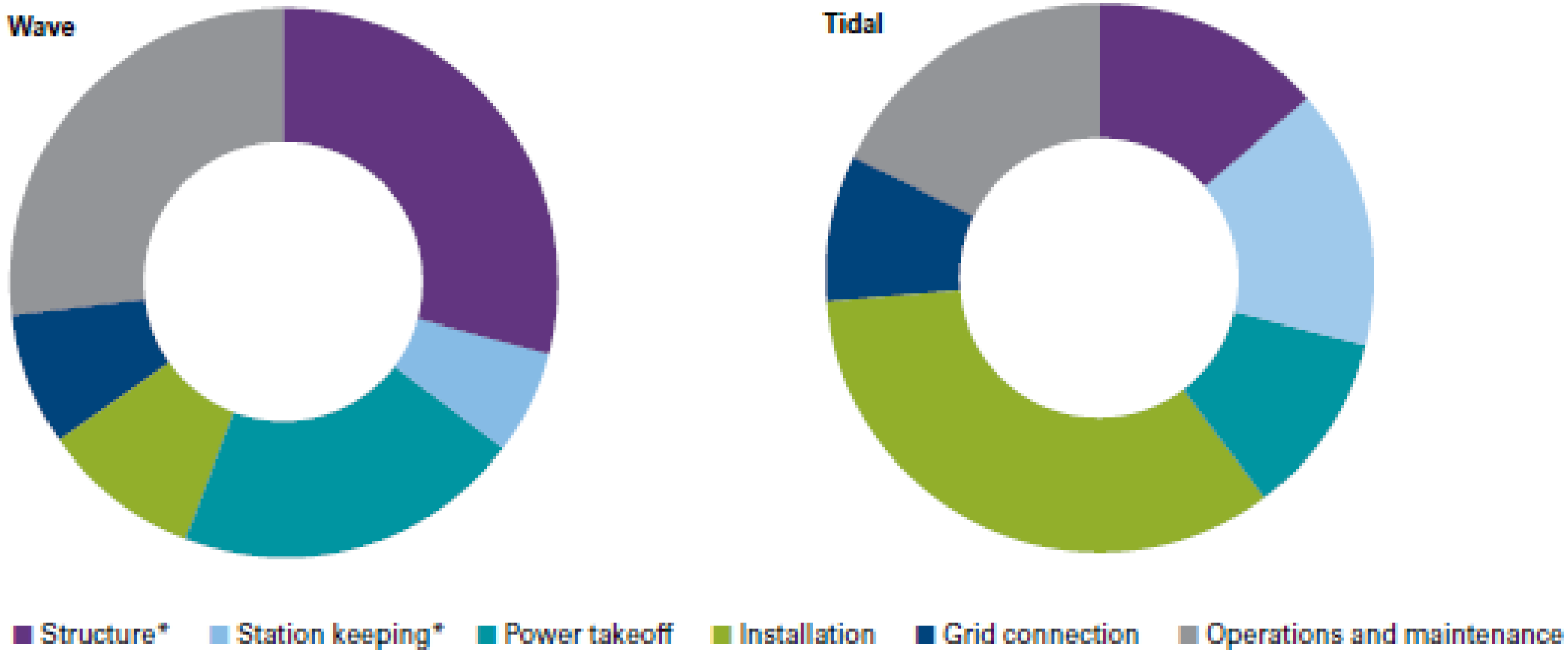
Updated MEA estimates of 'first farm' levelised cost of energy

Dark blue – base case, resource variation
Light blue – optimistic/pessimistic case, plus resource variation

Deployments of todays leading concepts in 10MW arrays, after 10MW of previous installations, using a 15% discount rate and 25 year lifetime.

The breakdown of levelised cost of energy helps set the agenda for cost reduction innovation

Figure 7a and 7b Indicative levelised cost of energy components for wave and tidal energy converters in an early commercial farm. The coloured segments are capital costs, while the grey segment represents O&M costs and includes all other spend including insurance and leases

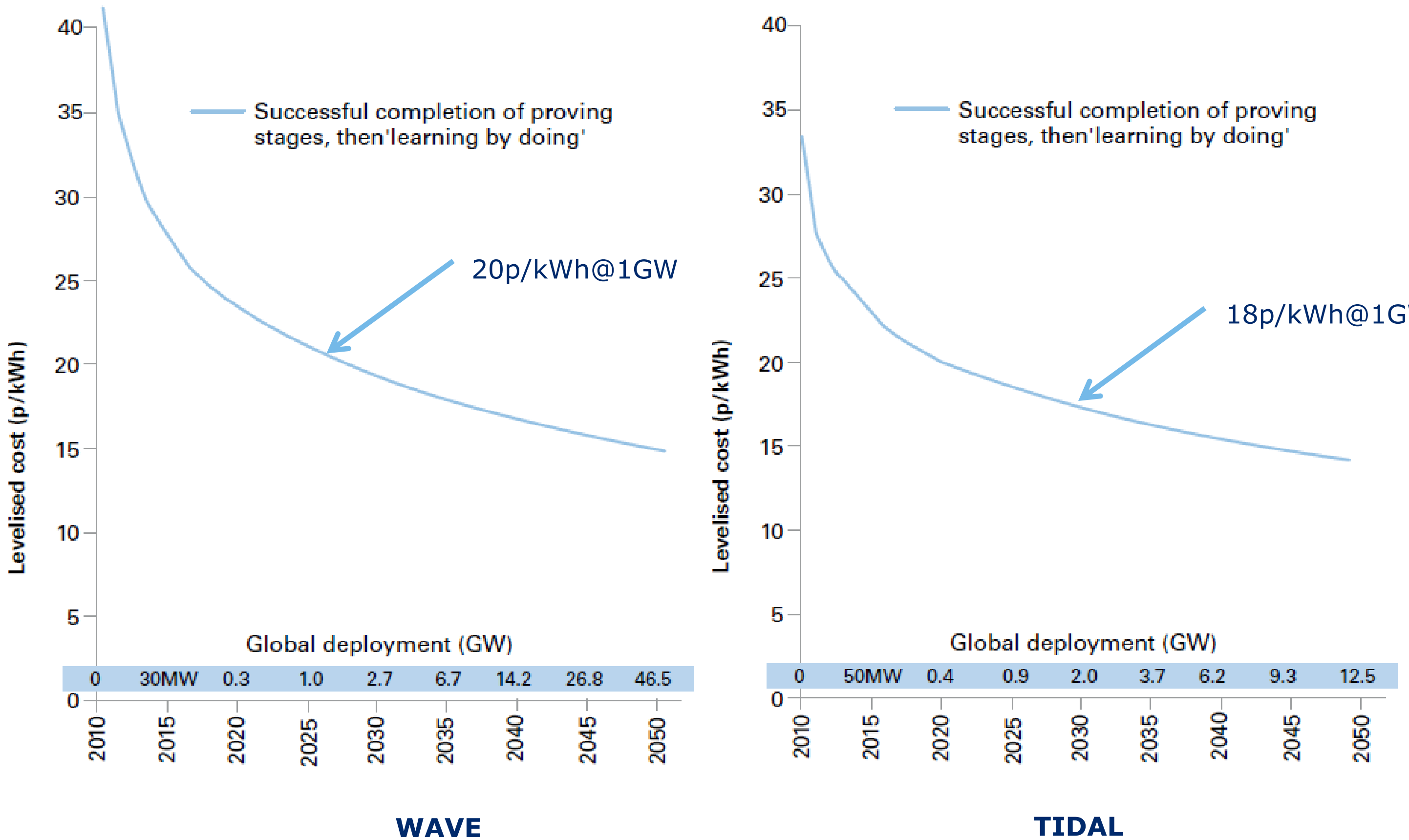


*Tidal Structures and Station Keeping may be combined in monopoile type designs.

- **Key cost areas for wave are: structure costs and O&M**
- **Key cost areas for tidal are: installation, foundations and O&M**

A "learning by doing" progression rate based on similar (but established) industries results high future costs

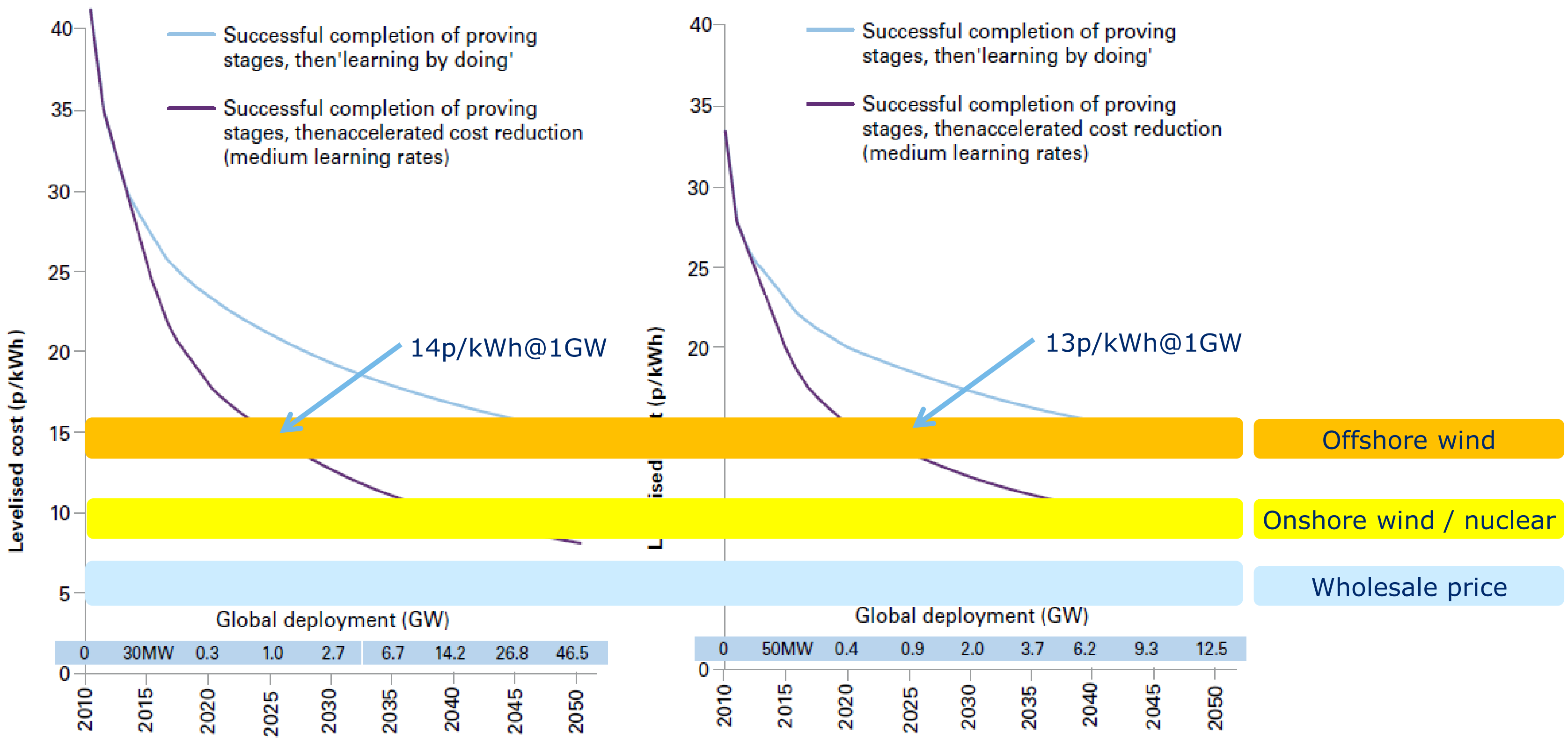
Figure 22 Baseline cost of energy reductions from wave and tidal devices, based on learning by doing only. Note that the roll-out rates for wave and tidal are different[30]



It is reasonable to expect a combination of "learning by doing" and "innovation" for wave and tidal

WAVE TIDAL

Figures 23a and 23b Possible cost reduction pathways for wave (left) and tidal stream energy under a 'business as usual' and innovation scenario

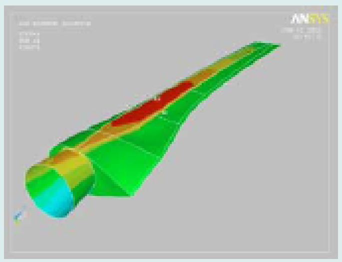


Note: Two proving stages exist, one at full-scale prototype, and one at first array stage.

Examples of targeted innovation for cost reduction from the MEA: Components

MEA project case study

Figure 16 Carbon fibre tidal turbine blade project, by Aviation Enterprises Ltd. AEL makes blades for several tidal stream developers

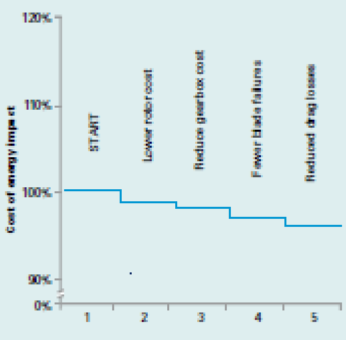


Tidal turbine blades – sequential testing and certification

No tidal stream turbine blades are yet proven in the marine environment. To certify that blades will last for the full life of the machine, sequential qualification is needed. This starts with verifying the fundamental properties of the material, its manufacture and its application and then the detailed design of the final assemblies. Without an understanding of the detailed behaviour of the material in real sea conditions, the blades are likely to be overdesigned and less efficient than they could be.

The AEL project has focused particularly on engineering of materials and joints, and on reducing manufacturing time to reduce costs.

AEL are now supplying carbon fibre blades for Marine Current Turbines and Tidal Generation Ltd (Rolls-Royce) and are in discussion with other leading tidal technology developers.



Impacts on the cost of energy

Reducing the overdesign of components reduces the quantity of material required, saving money. Reducing over-engineering can also make blades slimmer and so improve the performance, as well as reducing drag losses and the potential for cavitation.

Slimmer blades can be run faster, allowing a smaller, less expensive gearbox to be used.

A better understanding of the material, its behaviour, and likely failure modes can lead to better design and monitoring and ultimately higher reliability and fewer expensive blade failures.

In addition, if these issues are understood early on, there will be fewer blade failures that might otherwise harm the fragile development of the industry.

Towards cheaper and more reliable blades.

MEA project case study

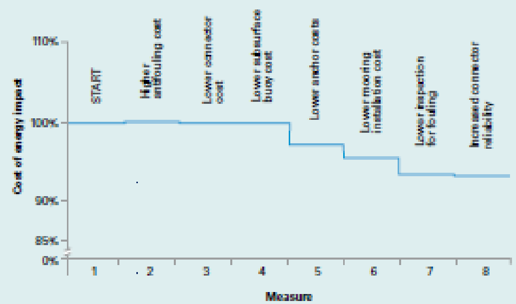
Figure 17 Nylon mooring rope study by Tension Technology International. Nylon mooring ropes (and associated anchors) could be applicable to all floating wave or tidal devices

Compliant lightweight fibre mooring system for floating devices

Most mooring systems consist of heavy metal cables with expensive anchors. TTI with partners Promoor have developed a new lightweight mooring system based on nylon ropes and gravity bag anchors. Nylon is more compliant than steel and can lead to lower loads on the moored device. Nylon is not yet in widespread use and so research into its fatigue performance was needed.

As part of the research TTI also investigated using fabric bags filled with aggregate to replace more expensive drag-embedment anchors or the more awkward to handle gravity anchors. The research also identified ways to prevent the highly compliant mooring system from bio-fouling by using a flexible protective coating.

Impacts on the cost of energy



Swapping to nylon from steel cable can lead to better mooring compliance and lower overall loads on the moored structure. Nylon has also been shown to have good fatigue resistance, meaning it is likely to last longer and need fewer inspections. The rope system is also cheaper than the steel equivalent.

The anti-fouling coating adds expense, but as it protects the rope, fewer costly inspections are needed and the rope is likely to be more reliable and last longer.

Fibre ropes are lighter and easier to handle during installation than steel equivalents. This leads to lower installation costs. Similarly, bag anchors are significantly less expensive and easier to handle during installation than drag anchors or equivalent gravity anchors.

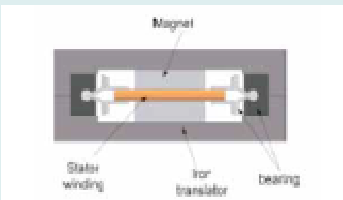
This work is currently progressing with further support from The Carbon Trust under the Entrepreneurs Fast Track scheme.

Lightweight compliant mooring for floating wave/tidal devices.

Examples of targeted innovation for cost reduction from the MEA: Components

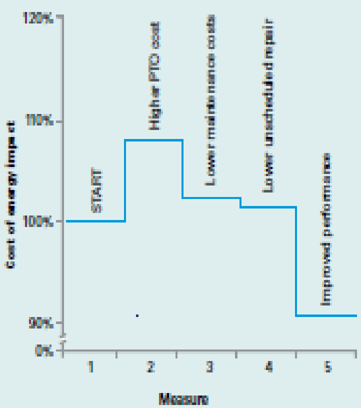
MEA project case study

Figure 18 Linear generator for wave devices (Edinburgh University)



Linear generator

Linear generators could be applied in many wave energy devices that currently use oil hydraulics. The University of Edinburgh has developed a novel linear generator system. This generator is simpler to construct and less costly than existing linear machines. This makes it a lower-risk alternative to hydraulics and brings forward the time when direct electrical connection can be used in wave devices.



Impacts on the cost of energy

The overall cost of a linear direct electrical machine is significantly higher than a hydraulic equivalent.

However, this new design has far fewer moving parts, which makes it more reliable.

There are far fewer parts to service, translation bearings being almost the only example, and no filters, seals, pumps or accumulators.

At part and variable load it is expected that this novel linear generator will be more efficient than a hydraulic equivalent.

At least three wave device developers are now looking at incorporating Edinburgh University's C-Gen linear motor into future generations of their devices.

Innovative linear generators for future wave devices

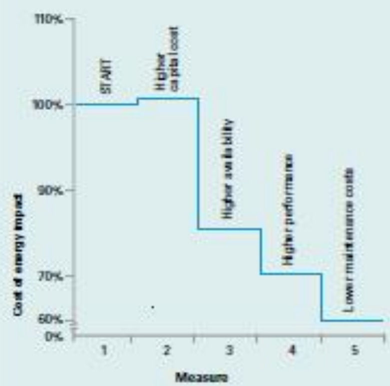
MEA project case study

Figure 21 Installation and connection component development for the Pelamis device.

Pelamis – enhanced installation and connection equipment

The Pelamis device is an attenuator made up of four large diameter steel cylinders connected via hydraulic rams which pump high-pressure fluid through hydraulic motors via smoothing accumulators. The current P2 commercial production machines are 180m long and 4m in diameter, have four PTOs and are rated at 750kW.

The Pelamis device is designed to be removed from its mooring and towed to a sheltered site for maintenance. Before this project, installation and maintenance of Pelamis devices required multiple specialised vessels and expertise, and was restricted to narrow sea condition windows and subject to high operational risk.



Impacts on the cost of energy

PWP undertook an extensive redesign of the offshore installation equipment, mooring connection components, and installation/disconnection procedures. This significantly widened the range of operating sea conditions in which P2 can safely be installed/disconnected,and greatly increased the proportion of the year that the P2 could be serviced while reducing the time spent waiting for suitable weather windows. As a result the predicted availability of the machines rose substantially.

PWP also considered an active 'yaw' system that enabled the device, at relatively little extra cost, to adjust its direction to suit the incoming waves. This increases the performance of the farm.

The simpler deployment and retrieval process means that fewer lower-specification vessels are needed, reducing the cost of each intervention.

When combined, these features can deliver around a 35% reduction in the cost of energy over the equivalent design used on the previous Pelamis version.

Installation and connection equipment for Pelamis has enabled operations in bigger seas, and faster deployment

Examples of targeted innovation for cost reduction from the MEA: New devices

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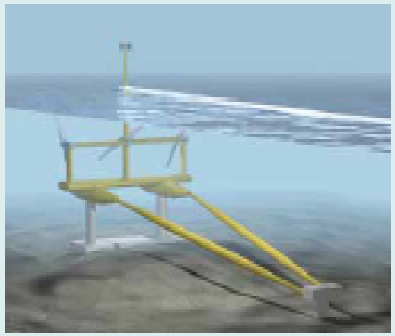
MEA project case study

Figure 33: Second-generation tidal example: Marine Current Turbine's future device concept contains multiple rotors on a single support structure and single foundation.

Marine Current Turbines second generation

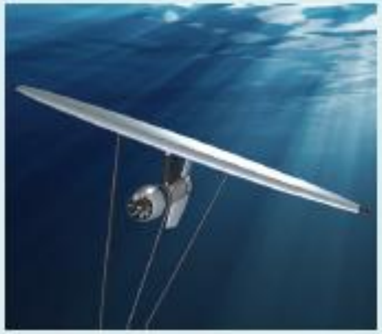


MCT's second-generation SeaGen-U device is envisaged as a multi-rotor device on a common support structure. This new device enables many rotors to be deployed in a single operation and addresses regions with water depths greater than 40m or extreme tidal range. One variant of this design is fully submerged with no surface-piercing element and addresses regions with water depths greater than 40m or extreme tidal range. The whole structure can be raised or lowered for maintenance.

The early development of the second generation device received funding from the MEA. The study estimated the cost of energy from three different foundation systems and deck structures, and included:

- A high-level review by each of the principal engineering disciplines to determine whether or not the concept is technically feasible.
- An independent review of the likely costs associated with the technology.
- A review of the increased market penetration SeaGen-U could expect as a result of the better suitability to attractive deep sites.
- Identification of the key issues, risks and opportunities.

2nd Generation tidal. Cheaper; deep and difficult sites



- an independent assessment of the likely achievable cost of energy
- an understanding of key issues, risks and opportunities
- recommendations for further work ,many of which have been taken forward by Minesto and by the Carbon Trust's Applied Research scheme.

Underwater Kite - '3rd' Generation tidal. Opens up low velocity resource

Figure 36 Anaconda rubber attenuator. Distensible Tube Wave Energy Converter. The Anaconda device is made primarily from rubber rather than steel. In the long-term there is great potential for significant cost reductions, as rubber is both comparatively cheap and comparatively easy to fabricate. But these cost advantages are not guaranteed and would only be achieved after a move to volume manufacturing. The MEA engagement with Anaconda developers Checkmate Sea Energy therefore concentrated on cost clarification and a manufacturability and durability assessment

Rubber sea-snake. Potential step-change in cost of wave energy

What's next for Tidal stream?
High velocities sites will ultimately have the best economics if we can tackle the risks and challenges

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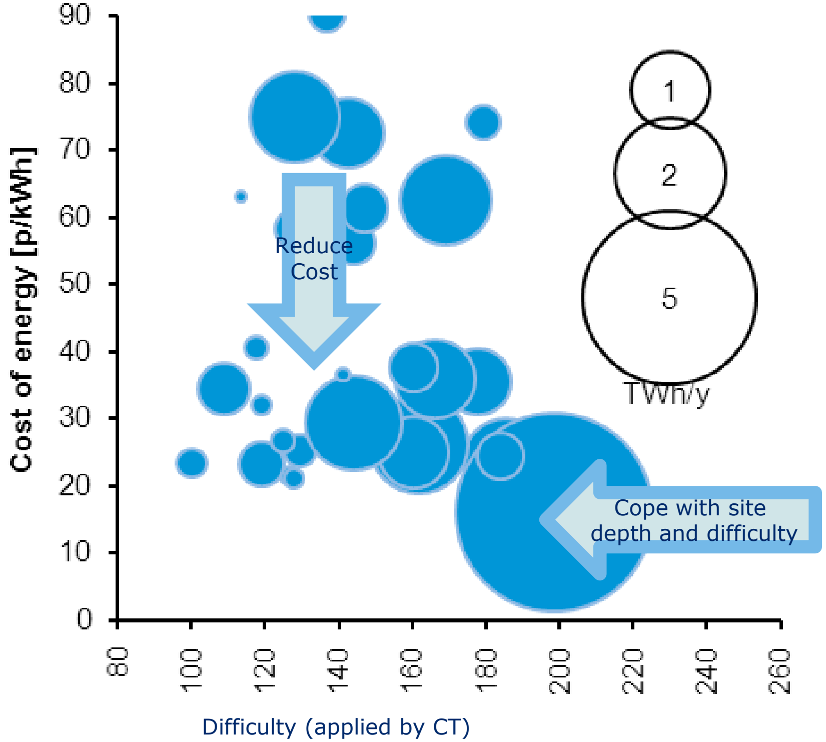
Much of the resource is in *difficult* or *deeper* sites.
A Second Generation of devices or approaches will be needed to access that resource.



Focus areas:

- Hours on the clock for leading technologies
- Multiple rotors per structure to reduce deployment and O&M costs
- Cost effective installation in difficult/deep sites
- Technologies which exploit the best part of the water column
- Specific challenges of building out first arrays
- Reliability
- Cabling at tidal sites

What's next for wave energy?
There is no fundamental reason why we need a 2nd gen technology

Focus areas:

- Hours on the clock for leading technologies
- Optimising coupling with the sea (fundamental hydrodynamics) - more power capture
- Device body / structure innovation (materials for cost reduction).
- O&M
- Proving survivability in more energetic seas
- Array behaviour
- Greater capacity devices
- Keep looking for that next gen lower cost device?

Accelerating Marine Energy available from the CT website: carbontrust.co.uk/marine

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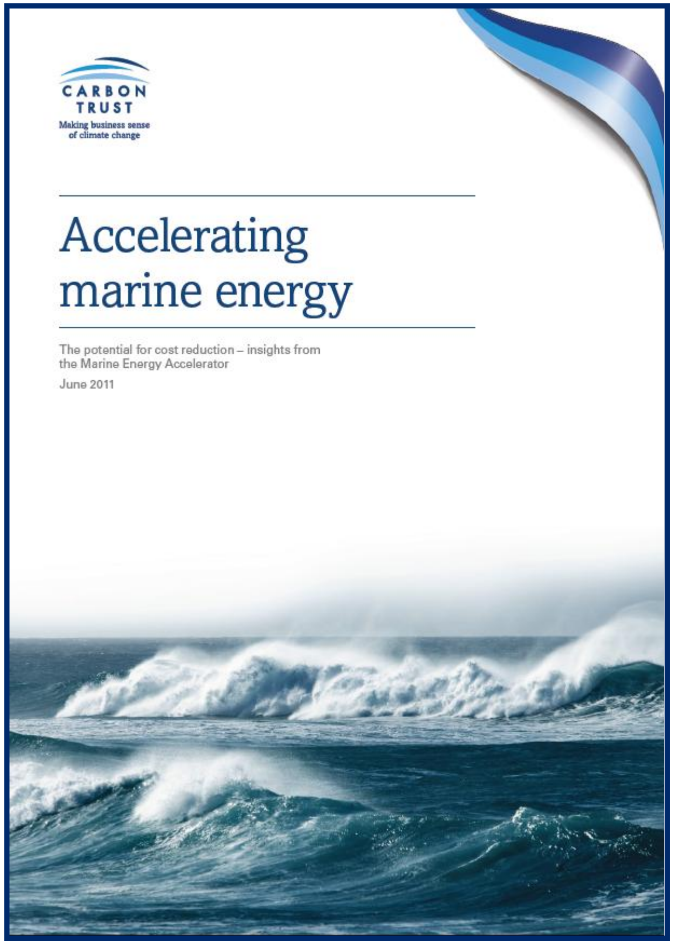

Final report – June/July 2011

Innovators

Aquamarine Power
Aviation Enterprises Ltd
AWS Ocean Energy Ltd
Checkmate Sea Energy Ltd
Cranfield University Ltd
C Wave Ltd
Hammerfest Strøm
Joules Energy / Wavetrain UK Ltd
JP Kenny
Mac Taggart Scott
Marine Current Turbines
Minesto
Ocean Power Technology UK Ltd
Pelamis Wave Power Ltd
Promoor Ltd
Sea Energy Associates Ltd
SeaKinetics Ltd
Tension Technology International Ltd
Tidal Energy Ltd
TNEI Services Ltd
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