A Route to the Cost-Effective Deployment of Large Arrays

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Atlantis Resources Corporation
**Atlantis** is the world’s **leading developer** of tidal current energy generation technology and ocean power projects in terms of turbine sales and seabed under management globally.

- Originator of **world’s** largest marine power project, MeyGen (398 MW) | Originator of **Asia’s** largest marine power project, Mundra (250MW)

**Business units:**

- **Turbine and equipment sales**
- **Consultancy services** – resource assessment, engineering design, techno-economic analysis, environmental assessment, installation management
- **Project origination** – greenfield projects sold to developers, governments and utilities
- **Research & Development** – ETI

**Global presence:**
- Asian HQ: **Singapore**
- UK HQ: London, **UK**
- Engineering Office: Bristol, **UK**
- Project Office: Sydney, **Australia**
- Project Office: EMEC, **Scotland**

**International test sites:**
- EMEC, **Scotland**
- San Remo, **Australia**
- FORCE, NS Canada
- Narec, **United Kingdom**
- Daishan, **China**
**AR-1500 Turbine**

- Detailed design by Atlantis and Lockheed Martin Corporation
- 1.5MW tidal turbine generation system rated at 3 m/s – the world's largest power single rotor turbine
- 18m diameter rotor diameter system
- Variable pitch
- 360° electric yaw drive
- Passive stab design for nacelle installation
- Connection Management System for subsea connection of power & telemetry
- Installation from DP vessel
The ETI Has Set Stretching Cost Reduction Objectives for Marine Renewables

**ETI & UK Energy Research Centre, ‘Marine Energy Technology Roadmap’**

**UK Deployment**
- **2010**
  - FULL-SCALE DEMO
  - 0 GW
- **2020**
  - SMALL ARRAYS (2-10 MW)
  - LARGE ARRAYS (10-100 MW)
  - 1-2 GW
  - ~250 - 450 MW pa (200 - 500 units pa)
- **2030**
  - RAPID BUILDTOU OF NEW PROJECTS
  - 6-12 GW
  - ~500 - 1200 MW pa (400 - 1500 units pa)
- **2040**
  - ASSET REPLACEMENT, REDUCING NUMBER OF NEW PROJECTS
  - 9-18 GW
  - ~150 - 300 MW pa (100 - 300 units pa)
- **2050**
  - 10-20 GW
  - ~600 - 1200 MW pa (500 - 1200 units pa)

**Technology & System Performance**

<table>
<thead>
<tr>
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<th>CURRENT ESTIMATES</th>
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<tbody>
<tr>
<td><strong>CAPEX</strong></td>
<td>4,000 – 7,000 £/kW</td>
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<tr>
<td><strong>O&amp;M Costs</strong></td>
<td>1.5 – 4.0 p/kWh</td>
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<tr>
<td><strong>Array Load Factor</strong></td>
<td>25 – 35 %</td>
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<tr>
<td><strong>Availability</strong></td>
<td>75 – 85 %</td>
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<tr>
<td><strong>Overall COE</strong></td>
<td>17 – 40 p/kWh</td>
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Source: ETI and UKERC, 2010
Traditional Route to Cost Reduction: Start with a Given Innovation and Optimise Around It

An Optimal Route to Cost Reduction: Take All Components and Configurations and Optimise for the Entire System

- Limited gains: May eventually yield a local minimum, but this is statistically unlikely to be the optimal solution
- Maximum potential gains: The most rigorous approach to finding the lowest cost of energy – best for the industry in the long term

The Atlantis team identified that it was not possible to meet the ETI’s objectives focusing on just a few components in the turbine array system – a holistic approach is required
Tidal Energy Converter System Demonstrator: A Pan Industry Project

Hydrodynamic Absorber
- Gurit
- ARL

Installation
- eta
- LOC
- mojo maritime
- Bluewater
- TidalStream
- Pelamis

Health & Safety Certification
- Collaton
- DNV

Power Take Off
- Rexroth Bosch Group
- Ricardo
- IHC Lagersmit
- Magnomatics
- SmartMotor

DEEPOCLEAN
- CONVERTTEAM
- MacArtney

Array Optimisation
- TidalStream

Fixation
- BAUER
- geo marine
- ritchies
- pelamis

Reaction System
- mojo maritime
- Sustainable Marine Technologies Ltd

Systems Integration
- Lockhead Martin

Project Management
- Black & Veatch
Lockheed Martin Turbine Array Performance (TAP) Model

- Lockheed Martin have brought their large-scale systems integration expertise to bear on tidal energy,

- TAP is a proprietary techno-economic model designed to optimise the configuration of tidal energy arrays

Calibrated with Empirical data

- For calibration, the model takes empirical input data from Atlantis’ AR1000 turbine

- Input data was provided by component suppliers in work packages ranging from seals and bearings to fixation and installation systems

Multiple Configurations and Scenarios

- Turbine configurations were be tested for a variety of blade lengths, water depths, wave loadings and tidal flows, for each set of component configurations

- Thousands of computational runs over several months.
Plenty of Cost Reduction Potential

Overall Learnings

- There is no single innovation that we have identified which can transform the economics of the industry alone

- Rather, a combination of cost-effective innovations, combined and optimised on a system-wide basis does deliver an attractive life cycle cost of energy

- Each component and innovation impacts the overall system – so it important to capture the interaction of effects. Together they can yield significant results

- Widely applicable results: the globally optimal solution “Preferred Architecture” was found to be optimal in 95% of the UK’s identified tidal sites

A Multi-variable Optimisation Exercise

- Mass
- Load cases
- Resonance modes
- Installation techniques
- O&M intervention intervals
- Failure modes
- Etc…

Optimisation feedback loop
Blades: Bigger is Better

Some received wisdom was validated, while other concepts were challenged:

- Bigger is better in terms of blade swept area; despite escalating power train costs in the nacelle, CoE for a 30m blade is less than the 18m blade. This holds true up to 30-35 diameter.
- Preservation of hydrodynamic profile, as close to the hub as possible, is a priority; over the blade’s design life this has a significant effect on CoE.
- Our studies indicate a cost of energy benefit of GRP (vs. carbon) for “skin”-type blades. This allows the hydrodynamic profile to be better maintained down to the hub.
Naval Architects such as Mojo Maritime are designing vessels optimised for the tidal environment:

- Tidal-optimised vessels can help reduce the costs of all subsea operations (installation, O&M, drilling and piling) by as much 50%.
- The vessels would be designed to operate in high flows up to 4-5 m/s and higher waves, circa 2 m Hs; this allows for a significant increase in availability.
- Better stability in off-axis flows
- Our modelling suggests availability could increase from 74% to 89% for installation and O&M interventions.
Electrical Observations:

- DC cables become economic around 70-80km from shore.
  - Cost and reliability challenges of DC power systems not preferred in architectures less than 70km from shore.
  - Improved transmission efficiency of DC outweighs its added cost in architectures over 80km.
  - Most of the tidal industry would benefit from AC transmission since most sites are closer than 70km from shore.

- An industry standard/convergence on electrical infrastructure design for arrays is needed
  - Technology Strategy Board has a project looking at this.
  - Need wider collaboration lead by government to continue to develop this.
Some received wisdom was validated, while other concepts were challenged:

- Centralised offshore power conditioning (PC) is essential for large tidal arrays…
- …but power conditioning on multi-rotor units is not always preferred for large tidal arrays.
- Depending on transmission voltage, optimal number of turbines to combine electrically is around 8 to 18.
- Multi-rotor PC Units require more individual subsea electronics containers to achieve the “magic number” of combined turbines.
- Since a centralised interconnect platform is already necessary, moving all PC equipment to the central location is economical.
We Have Identified an Architecture Offering an Attractive Cost of Energy Which Can be Delivered by 2020

A powerful and robust conclusion:
- Marine energy can deliver an attractive and sustainable cost of energy comfortably within the range of 9-18p/kWh
- And we have an architecture to deliver it
- Marine energy has an attractive future
...The Next Step is to Demonstrate It

- Outline Design (Q3 2013)
- Deliverables under review by ETI (Ongoing)
- Unveiling of the Preferred Architecture by the ETI (Early 2014)
- Detailed Design for Full Scale Demonstrator (2014)
  - Full Scale Prototype will demonstrate 80% of 2020 benefits in 2015
- Build and deployment of Full Scale Demonstrator in the UK (2015-16)