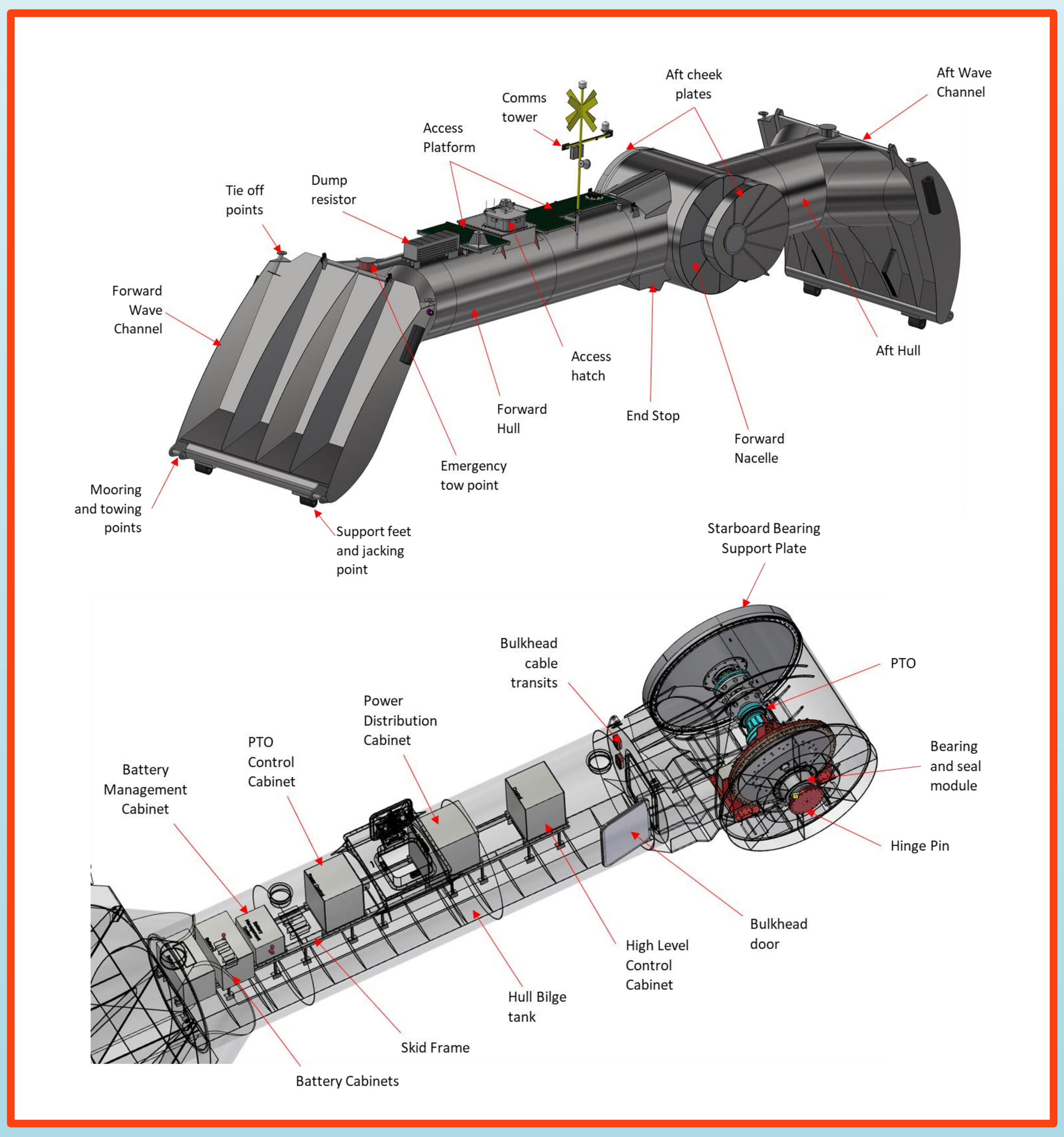
Fourth Annual Conference
#WESAC19

NWEC3: M100P Wave Energy Converter

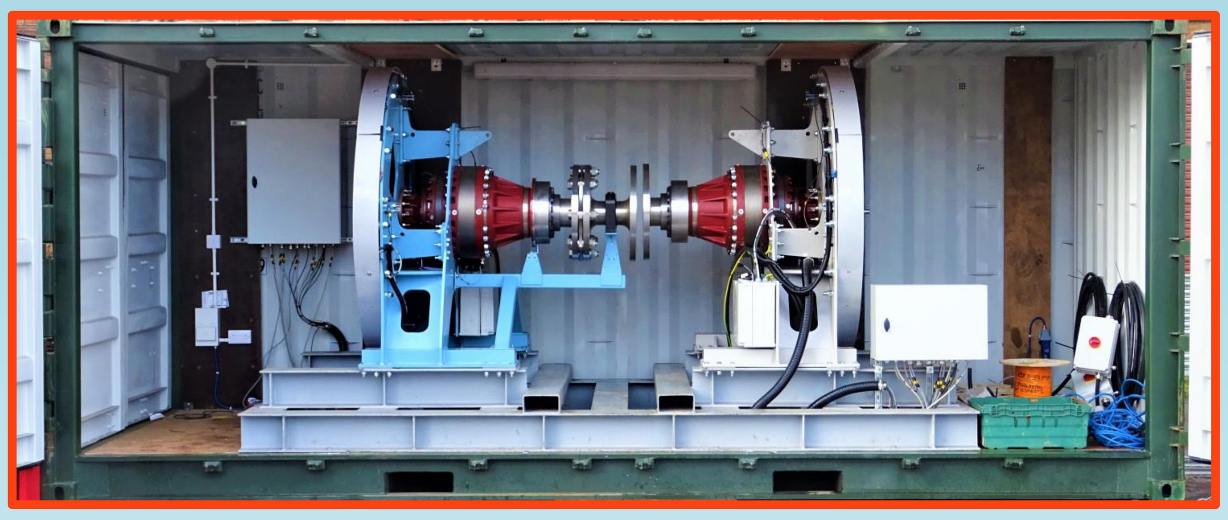
Introduction

The Mocean wave energy converter (WEC) is a hinged raft device. The dynamic response of the raft's two bodies to waves flexes the hinge, where an electro-mechanical power take-off converts the kinetic energy into electricity. The Mocean innovation is in the unusual shape of the WEC, which both increases and couples the motions in pitch, heave and surge of the two bodies. So, although the power take-off is solely in flex, we can broaden the resonant response to include wavelengths that are much longer than the overall length of the machine. This multiplies the total energy captured by many times compared to a standard hinged raft.

Feb 2019
Tank Testing

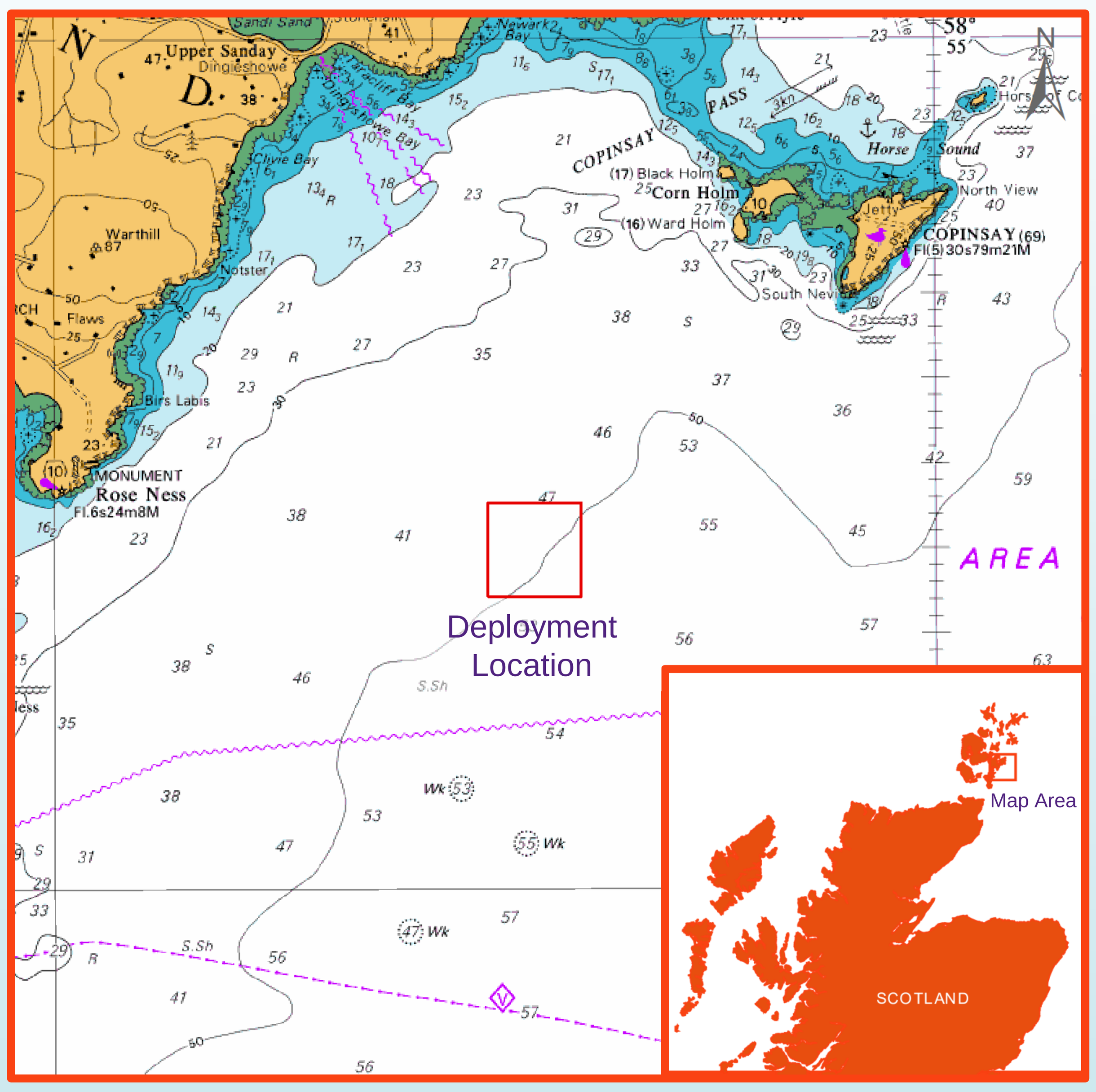


Apr 2019 – Mar 2020
Detailed Design, Fabrication & Assembly

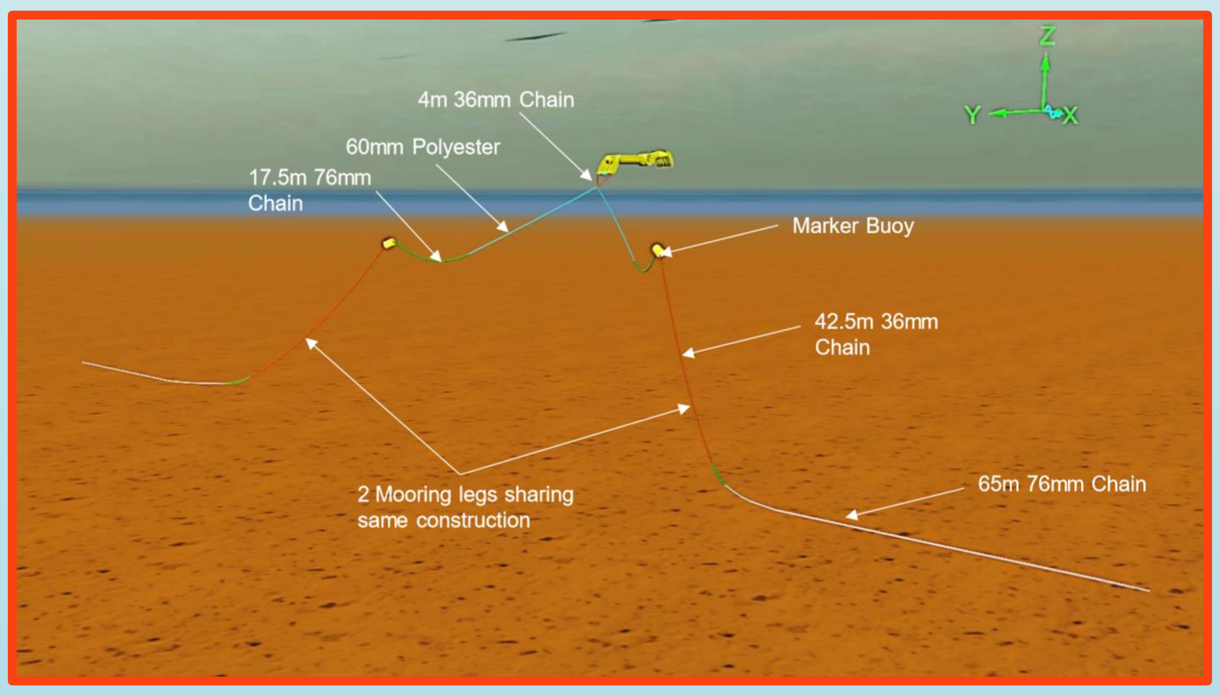


Nov 2019 – Dec 2019
C-GEN Generators Back-to-Back Testing

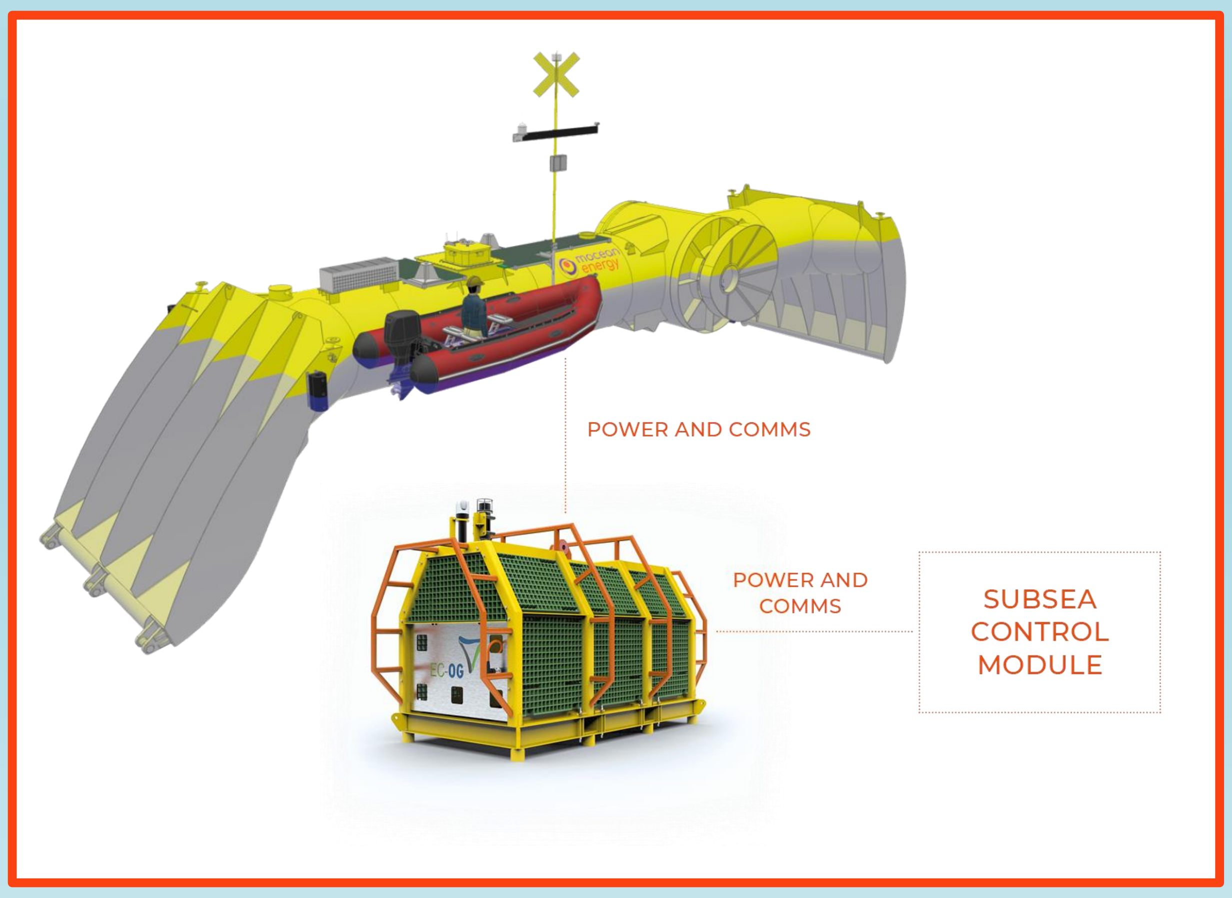
Feb 2020
Deployment Site Consenting Target Date [Orkney Islands]



Mar 2020
Mooring Deployment



Apr 2020 Onwards
Device Testing & Future Development



Lead Contractor

- Mocean Energy

Subcontractors

- AJS Production
- Aquatera
- Blackfish Engineering Design
- Fountain Design
- Industrial Systems & Control
- Leask Marine
- Maestro Marine
- Oceaneering
- Orcades Marine
- Sequentec
- Supply Design
- University of Edinburgh

LEAD CONTRACTOR:

mocean energy

hello@mocean.energy
+44 (0)131 651 7959

SUBCONTRACTORS:

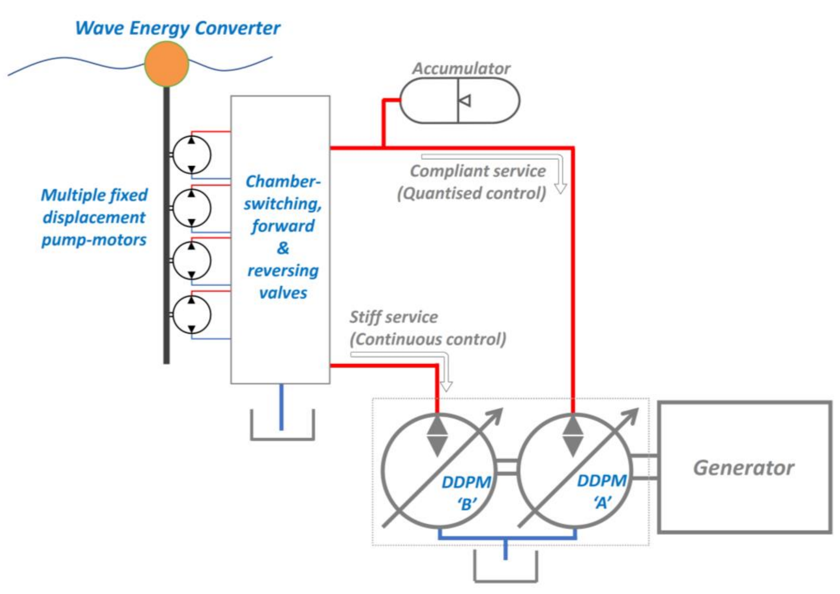
Quantor Hybrid Hydraulic PTO

WES Power Take-Off Systems, Stage 3

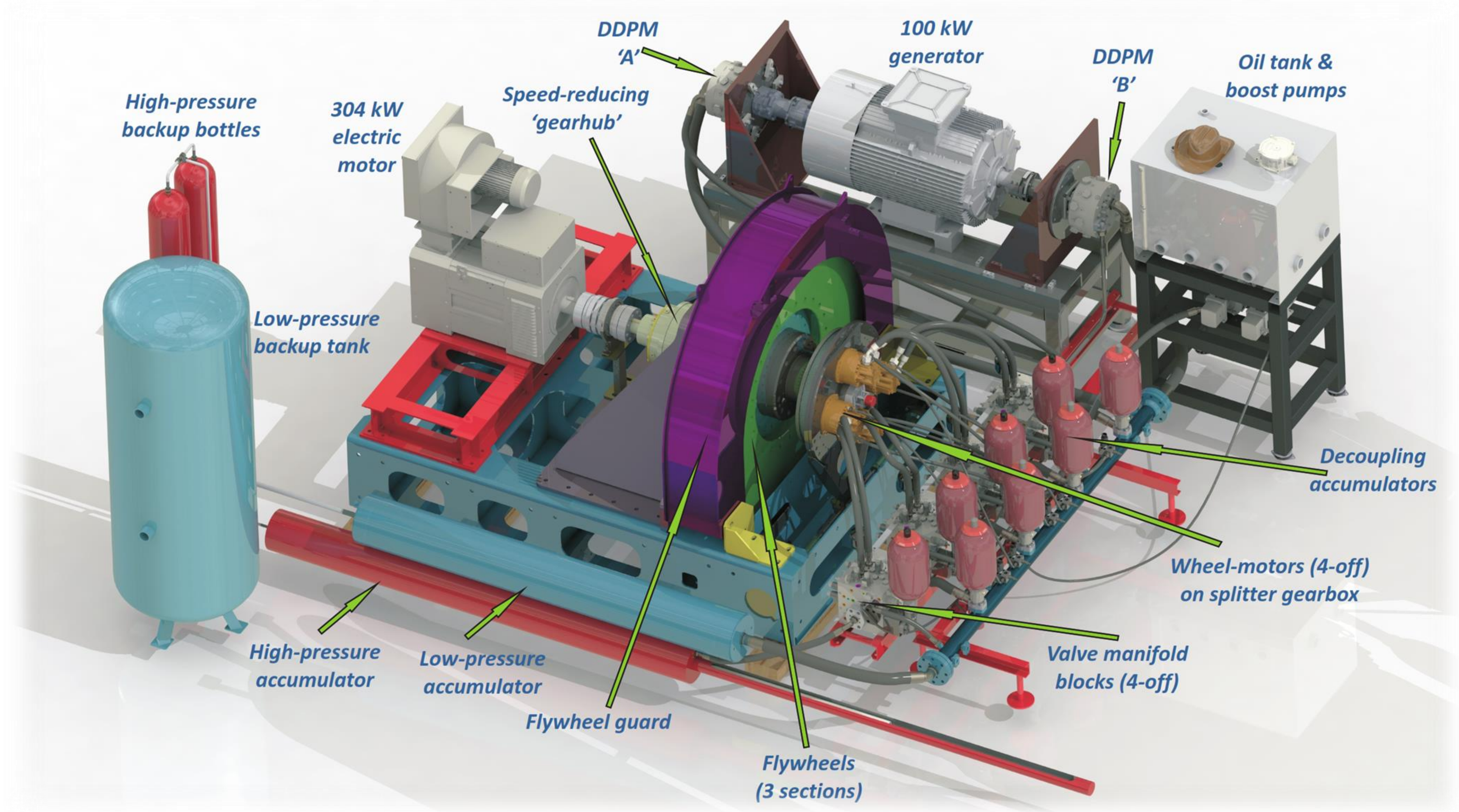
Introduction

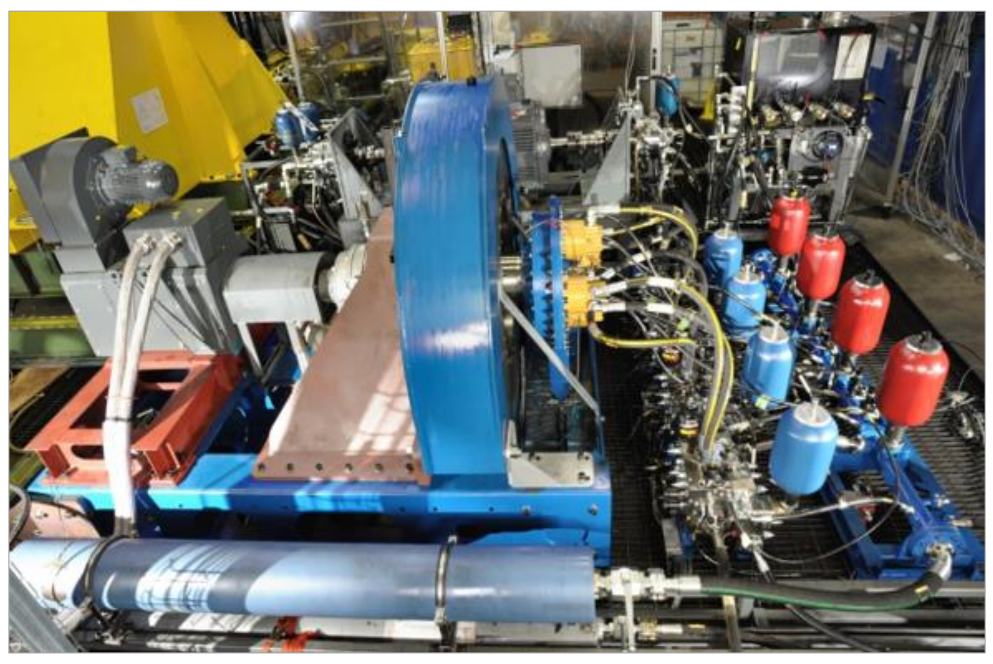
Artemis Intelligent Power and Quoceant have successfully demonstrated a new type of hydraulic power take-off system. ***Quantor*** combines the switched digital control of multiple hydraulic actuators, as previously demonstrated on the Pelamis WEC, with the continuous pressure control of Artemis Digital Displacement (DD) technology. This hybrid approach provides the enormous instantaneous power and load capability, smooth 4-quadrant load control, and smooth output at high average efficiency required for general wave energy application

Quantor can be rated over a wide range of forces, speeds, and powers by integrating with different types and numbers of actuators.



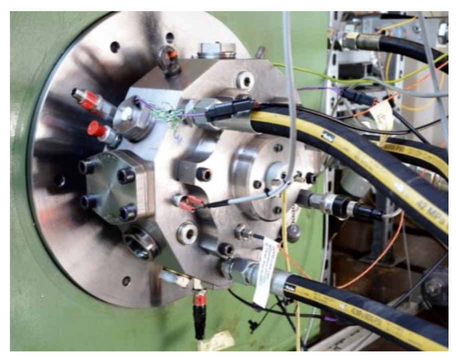
Left: The operating principle of Quantor. Multiple fixed-displacement actuators exchange power with the energy storage accumulator under quantised control. A transforming pair of DD machines fill in the gap between the smooth demand load and the quantised load using one or more of the actuators, whilst also generating smooth output power.



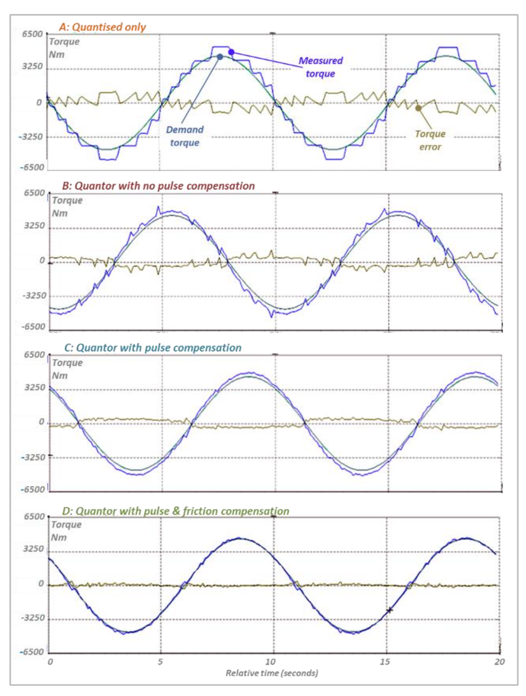


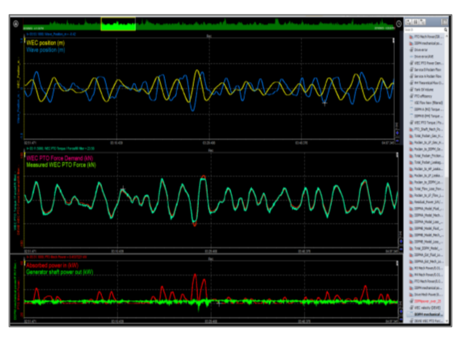
Electrically driven test rig with Quantor hydraulic PTO. A bi-directional flywheel emulates the WEC's inertia. Energy is captured by hydraulic 'wheel-motors', connected via control manifold blocks to combinations of 'quantised' and continuous pressure control.

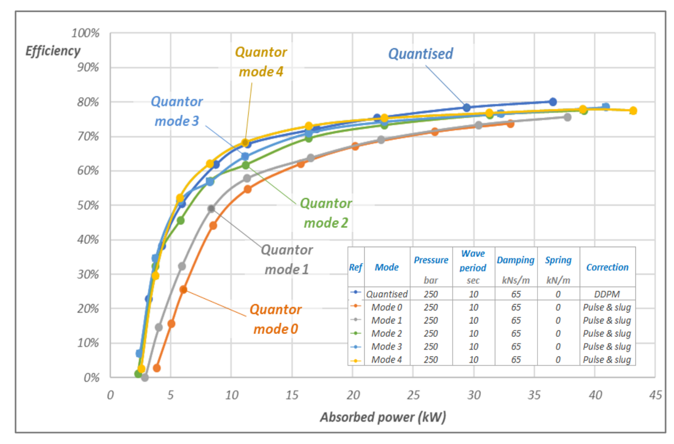
Quantised control transfers wheel-motor power directly to the high-pressure accumulator.



(left) The Digital Displacement pump-motors (DDPMs) provide continuous load control, pressure-transformation and generator drive.







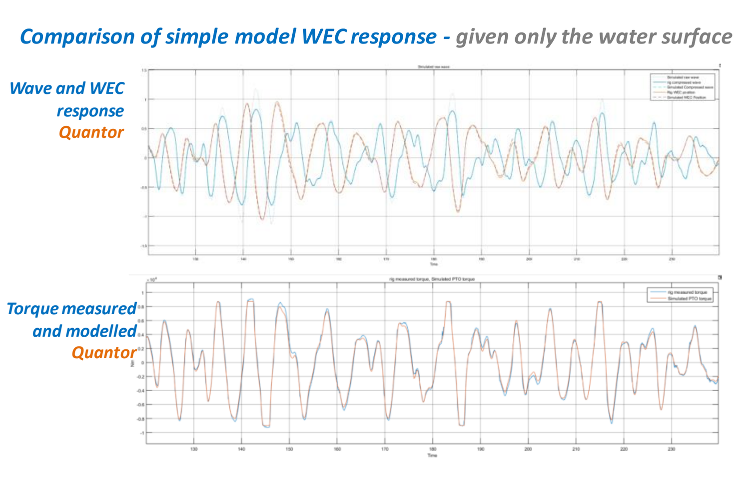
Above: (left) Measurements showing the Quantor PTO producing smooth controllable torque through progressive enhancements. (middle) Real time measurements of WEC response emulation in irregular seas (right) Measured efficiency versus absorbed power in regular wave characterisation tests from the small-scale rig system. Larger systems offer substantially higher efficiency up into the MW range.

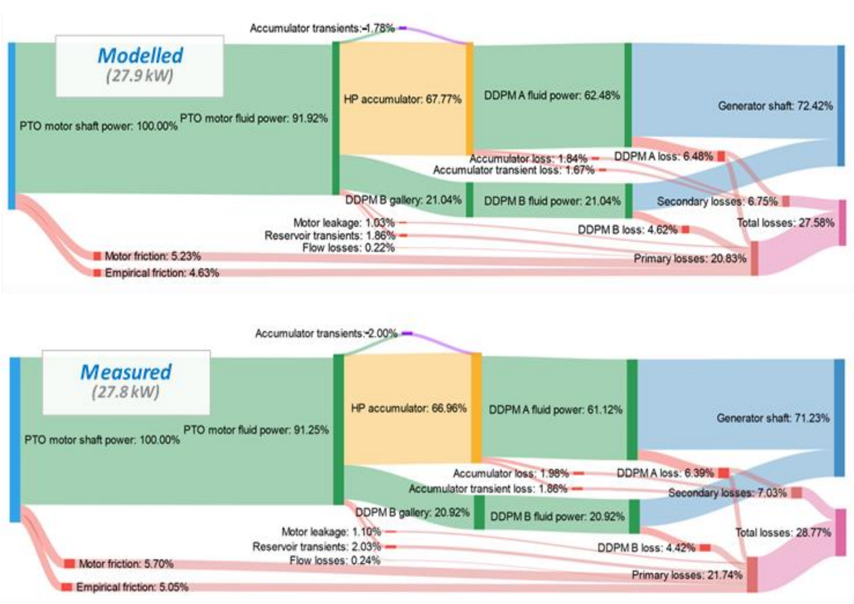
Testing and validation

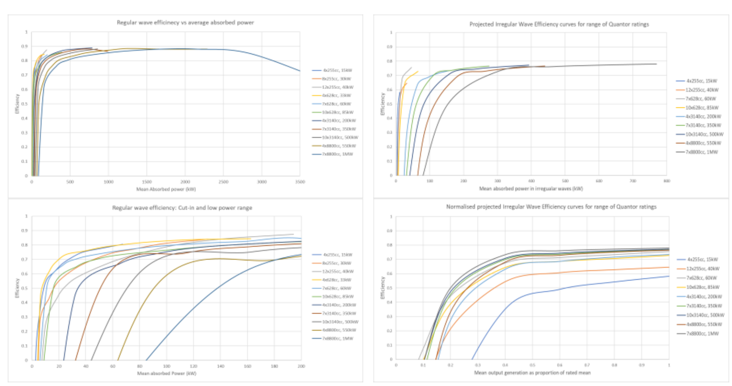
Artemis and Quoceant created a unique test facility to develop, demonstrate, and characterize the Quantor PTO in realistic operating conditions. The test-rig's electric drive-system emulates the wave induced motions and inertial behavior of a wave energy converter (WEC).

Detailed and accurate simulation models were developed and validated during the stage 3 project, and extrapolated to represent a wide-ranging family of Quantor solutions.

Below: (right) Sankey diagrams of measured performance of Quantor PTO smooth torque control at 28kW absorption. The DDPMs are recycling reactive power to provide smooth output on average. The model is only fed the same shaft input speed but recreates all loss details and time dependent behavior (left).



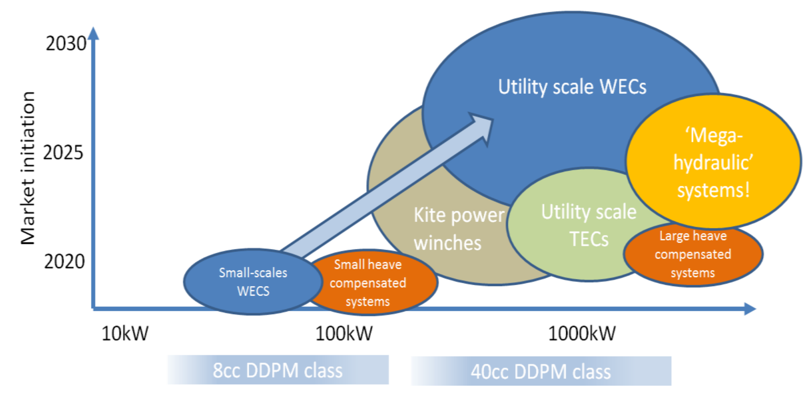


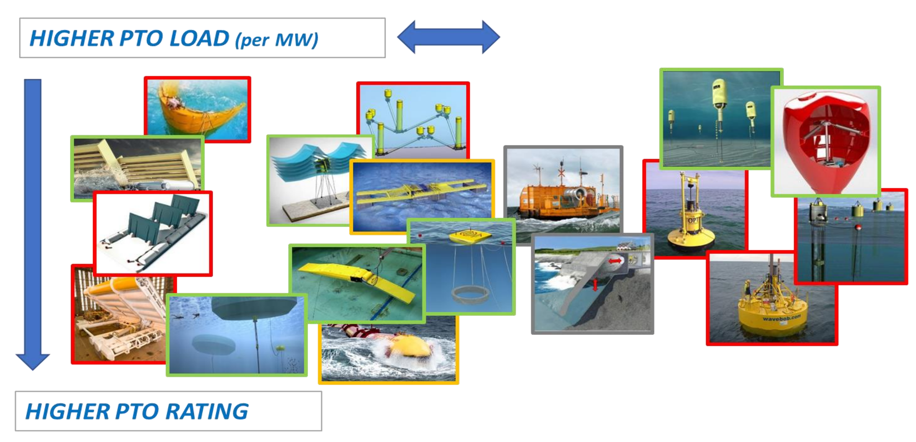


(left) The validated component levels model is used to produce performance projections for larger systems. Efficiency at lower power dominates the average efficiency in realistic wave conditions.

Commercialisation

Components and integration technology were also developed and modelled up to the MW power levels required for commercial wave energy.





(Above) Illustrating the envisaged range of markets for Quantor technology. (right) the range of WEC applications, including rotary and linear actuations, over a range of force and speed combinations.

ARTEMIS INTELLIGENT POWER
www.artemisip.com
Leading hydraulic power into the digital age
Quoceant Innovation Offshore
www.quoceant.com
Engineering Consultants

More information:
Ross Henderson, Quoceant Ltd.
r.henderson@quoceant.com

PECMAG

POWER ELECTRONIC CONTROLLED MAGNETIC GEAR

Introduction

The PECMAG PTO is a modular all-electric system comprising a magnetic gear and permanent magnet generator coupled to an integrated electronic rectifier and control system. PECMAG is being developed to suit a variety of WEC devices with both linear and rotary options available.

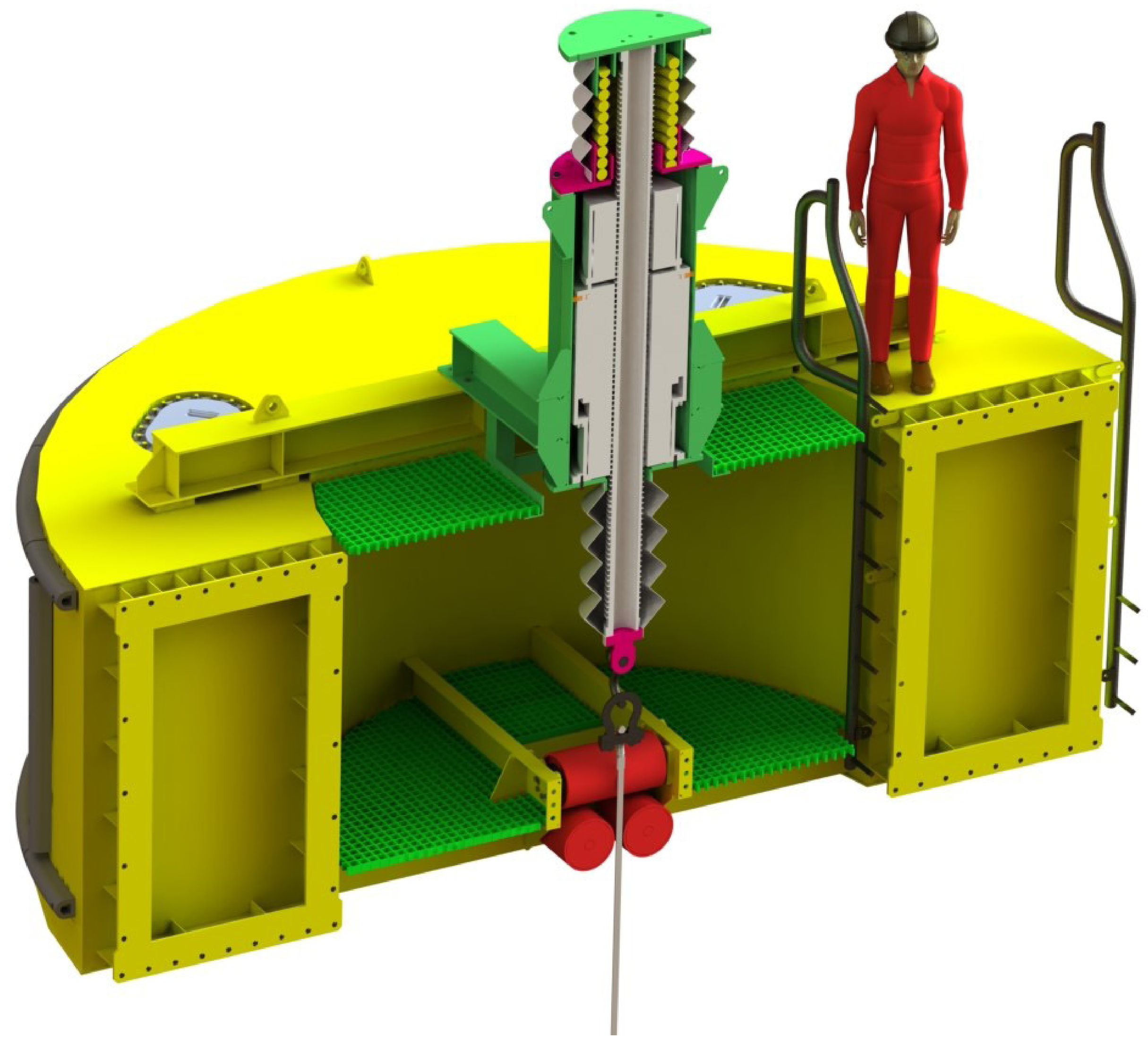
Key Features:

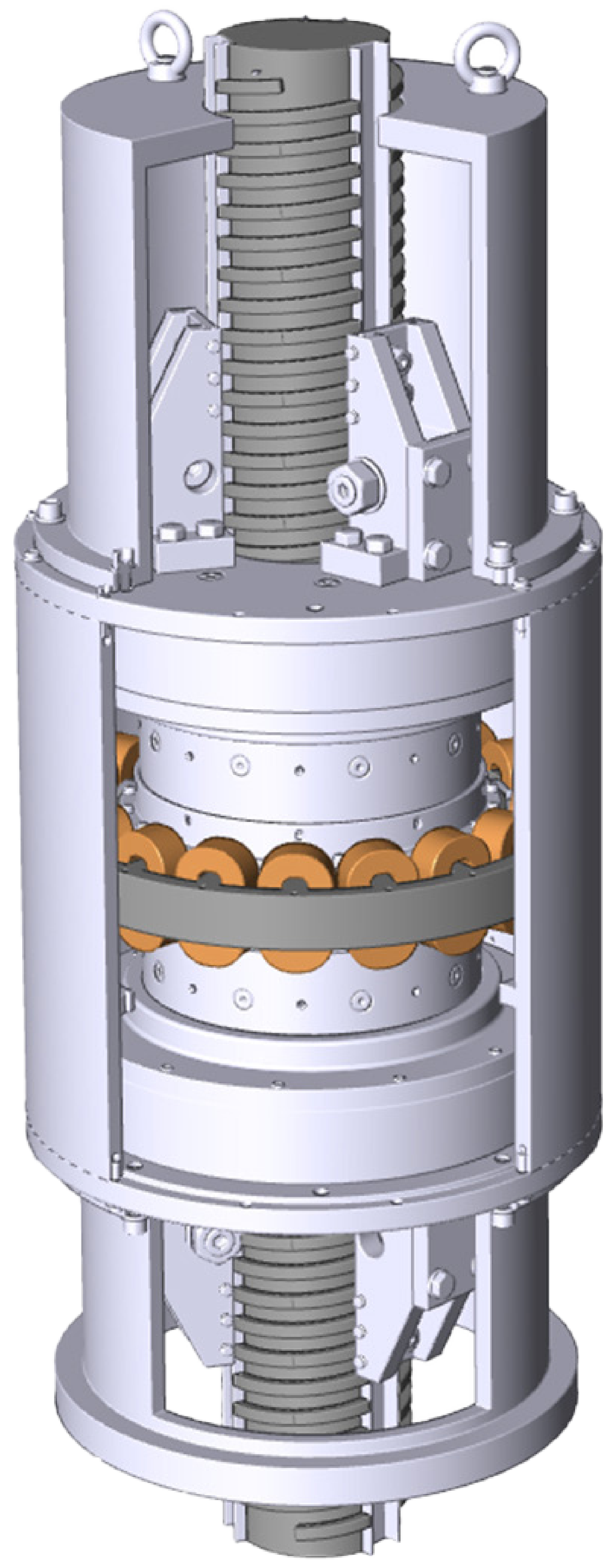
» SURVIVABILITY
Non contact design offers damage free slipping in extreme sea states

» COMPACT
At least 10 x smaller than equivalent direct drive system. High gearing achieved in a single stage

» INTEGRATED
Highly scalable, modular power electronics to maximise capture efficiency and availability. Rectifier >97% peak efficiency

» COMPATIBILITY
Straightforward integration with a variety of WEC types. Architecture supports complex non-linear control





Stage 3 Project - Addresses the key risks associated with PTO development through:

Advanced R&D: Improve performance & scalability

- Refined generator and gear component design and manufacture
- Segmented assembly simplifying repair and maintenance
- Modular power sharing and degraded performance optimisation
- Novel control algorithms to optimise energy capture in prevailing sea-states
- Improved speed, acceleration and force capabilities

Extensive onshore and offshore testing: Increase TRL and reduce investor risk

- Develop a 10kW rated machine suitable for deployment on pre-commercial demonstrators
- Demonstrate key slip and power capture features
- Deliver a PTO that can successfully integrate into a WEC system
- Validate marinisation approach and seagoing operability
- Allow reliability and availability metrics to be quantified

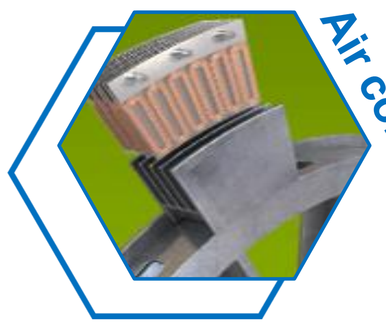
Subcontractors
Bathwick Electrical Design
Supply Design
Pure Marine Gen

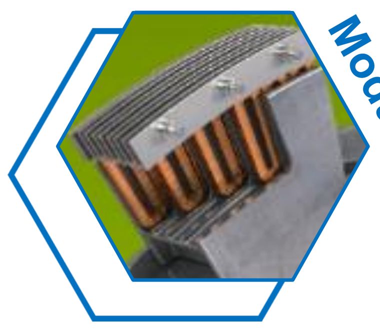
Mark Brown
mbrown4@oceaneering.com

Project Neptune – 75kW Linear Generator Test Rig

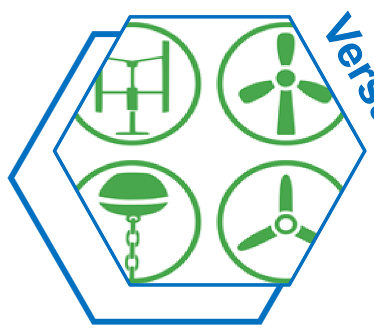
C-GEN is an advanced multi-stage air-cored direct drive permanent magnet generator technology providing high reliability and availability in renewable energy converters. Project Neptune was a Wave Energy Scotland Stage 3 PTO project which focused on the design, build and testing of 75kW reciprocating linear generator test rig for fully flooded operation.

Space for Tablet Screen


Air cored

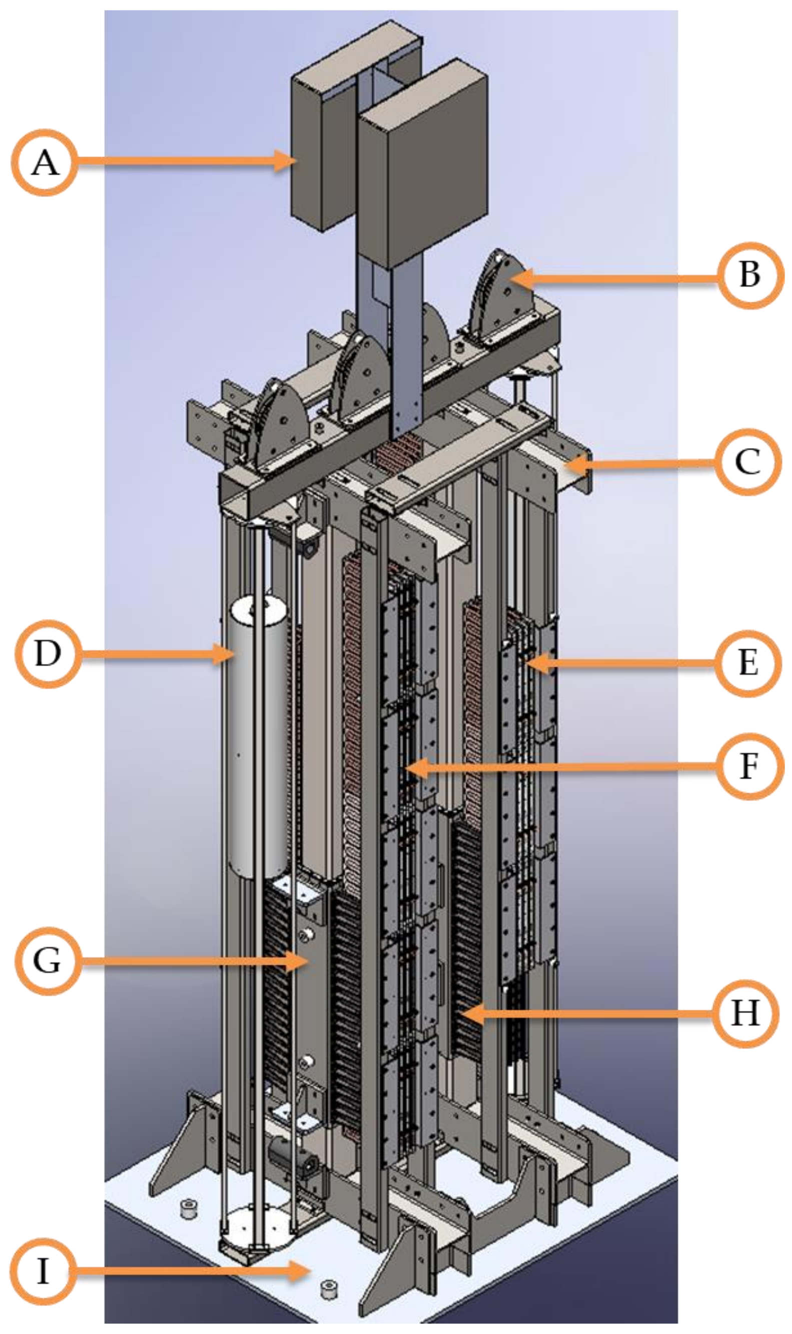

Modular


Stackable


Versatile

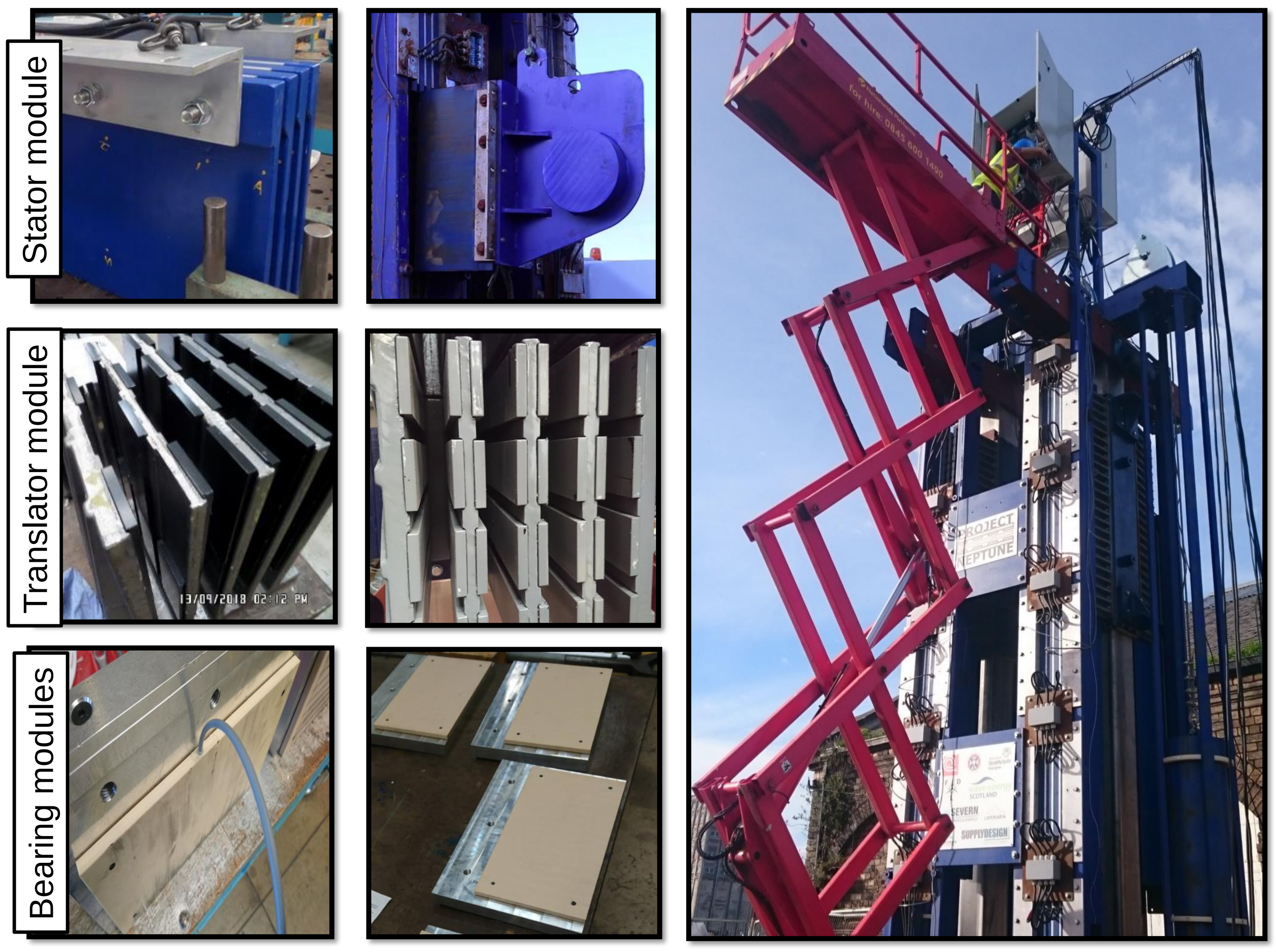
"The C-Gen system is highly versatile and can be applied in linear, rotary and part-rotary arrangements"

	Component Description
A	Data acquisition and power distribution boards
B	Translator/counterweight pulley system
C	Back to back motor generator test rig support structure
D	Counter weight 1, counter weight 2 on opposite side.
E	Generator coil modules potted in epoxy material. 3x 4 stage modules per machine
F	Motor coil modules potted in epoxy material. 5x 4 stage modules per machine
G & H	Translator 1 & 2 directly coupled to each other with motor and generator cast iron PM modules, polymer bearing modules and end stops
I	Test rig base plate

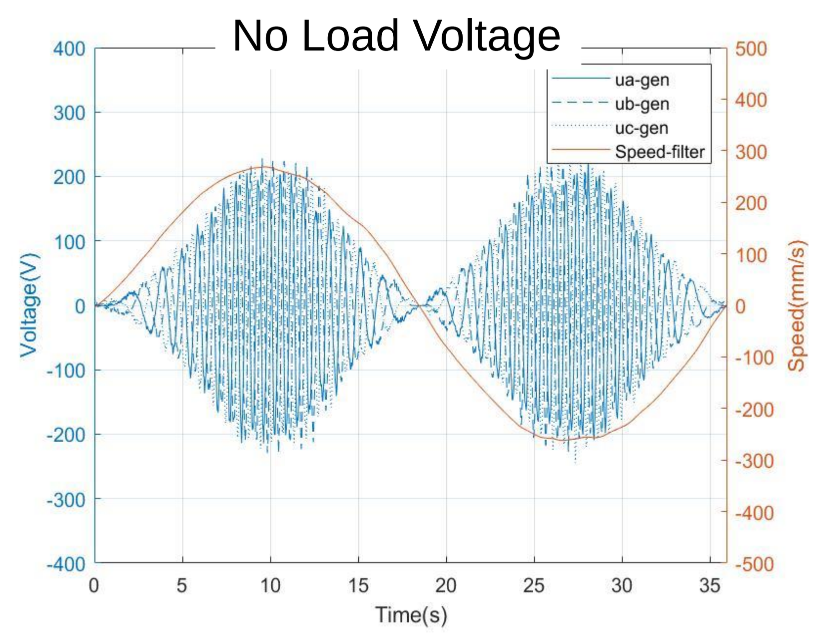


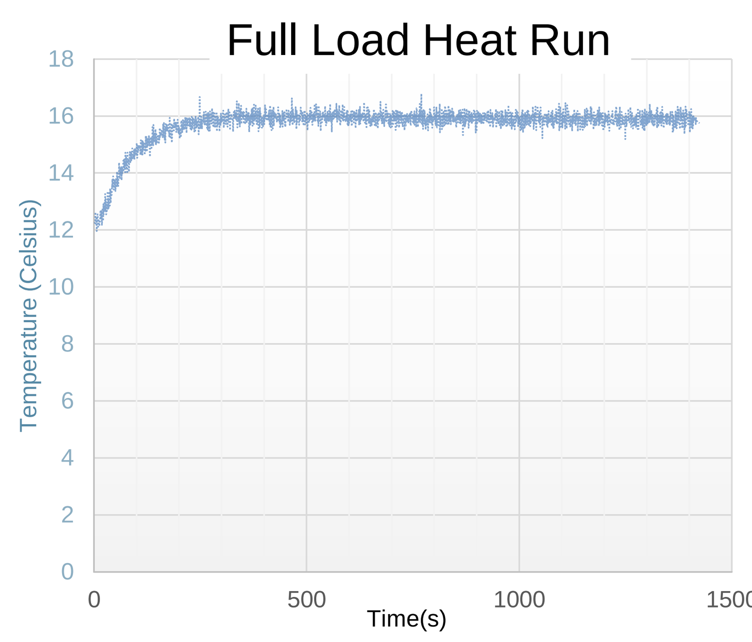
Project Neptune Objectives

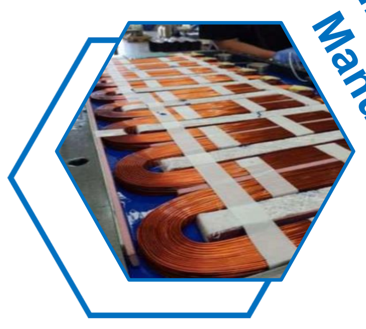
- Demonstrate a Linear C-GEN Generator in a **Real Environment**, at a **Relevant Scale** and under **Realistic Load Profiles**.
- Industrialise the Design & Manufacture of C-GEN for Marine Renewable Applications.
- Obtain Qualification from an Independent Body.
- Align the **Commercial Strategy** with **Device Developers** towards **Full-Scale Demonstrator**.

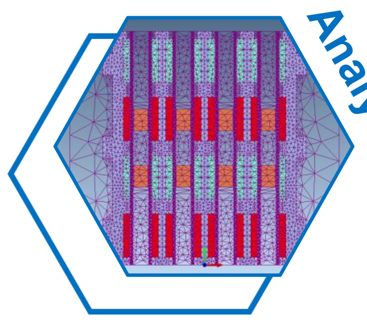


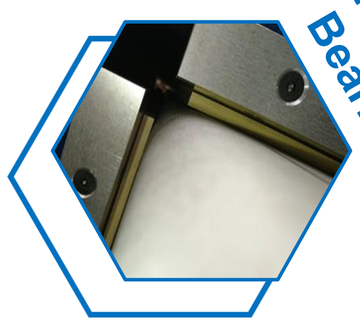
Result Snapshot






Industrial Manufacture


Analysis


Polymer Bearings


Testing

Project Neptune Outcomes

- Improved performance from dry to wet operation
- Fully flooded operation completed proving low temperature operation leads to an inherent overload capability and lower losses
- Module maintenance proven – low MTTR

Project Neptune Partners and Subcontractors

- **Fountain Design Limited**
- **Quartz Elec**
- **University of Strathclyde**
- **Severn Drives & Energy**
- **Supply Design Ltd**
- **Laminaria**
- **Carnegie**
- **Port of Leith**

Subcontractors

- **Bernard Hunter Cranes**

FDL RENEWABLE ENERGY DEVELOPMENT · quartz elec · SUPPLYDESIGN BESPOKE ELECTRONICS · SEVERN DRIVES & ENERGY · University of Strathclyde Glasgow · Carnegie CLEAN ENERGY · LAMINARIA

THE UNIVERSITY of EDINBURGH
School of Engineering

Dr. Joseph Burchell
j.burchell@ed.ac.uk

Prof. Markus Mueller
m.mueller@ed.ac.uk

wave energy SCOTLAND

EMERGE
Electro-MEchanical Reciprocating GEnerator
emerge (/ɪˈmɜːdʒ/): to appear, or to become recognized

Fourth Annual Conference
WESAC19

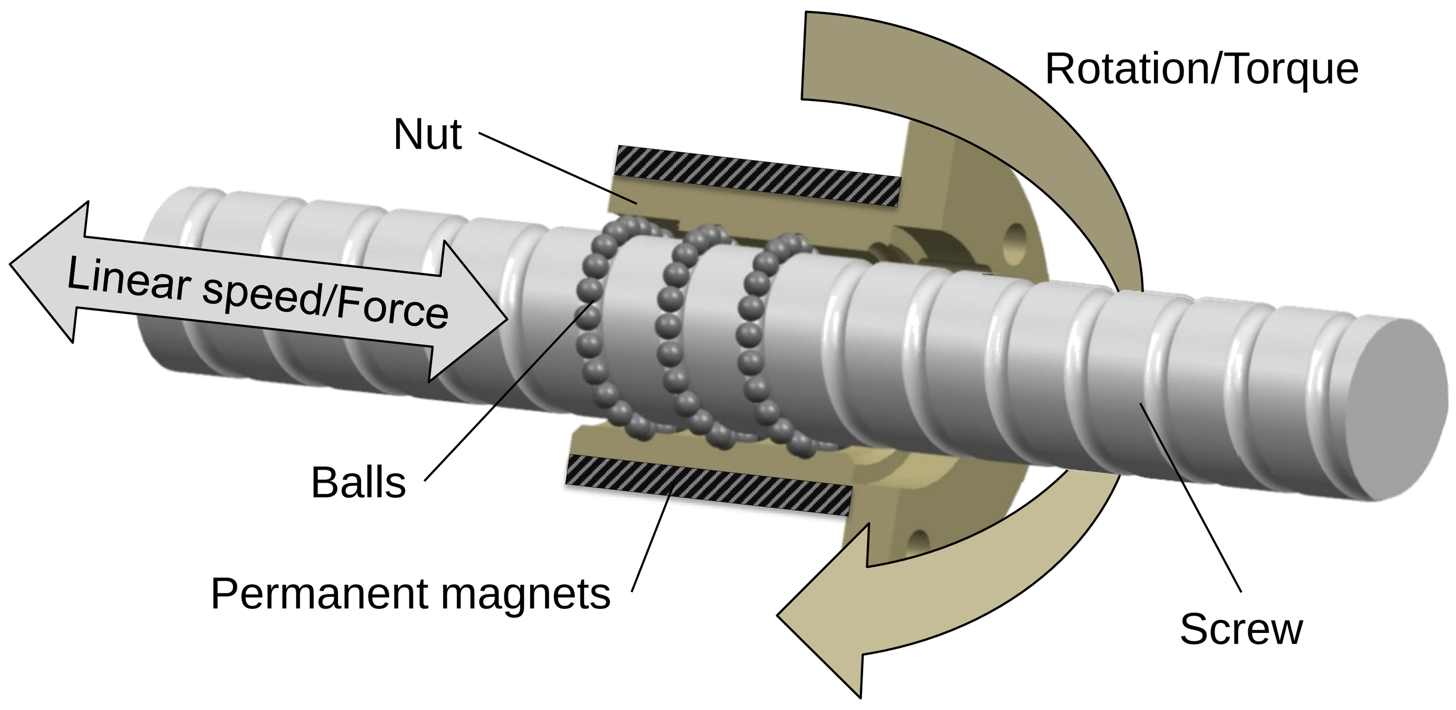
Electro-MEchanical Reciprocating GEnerator

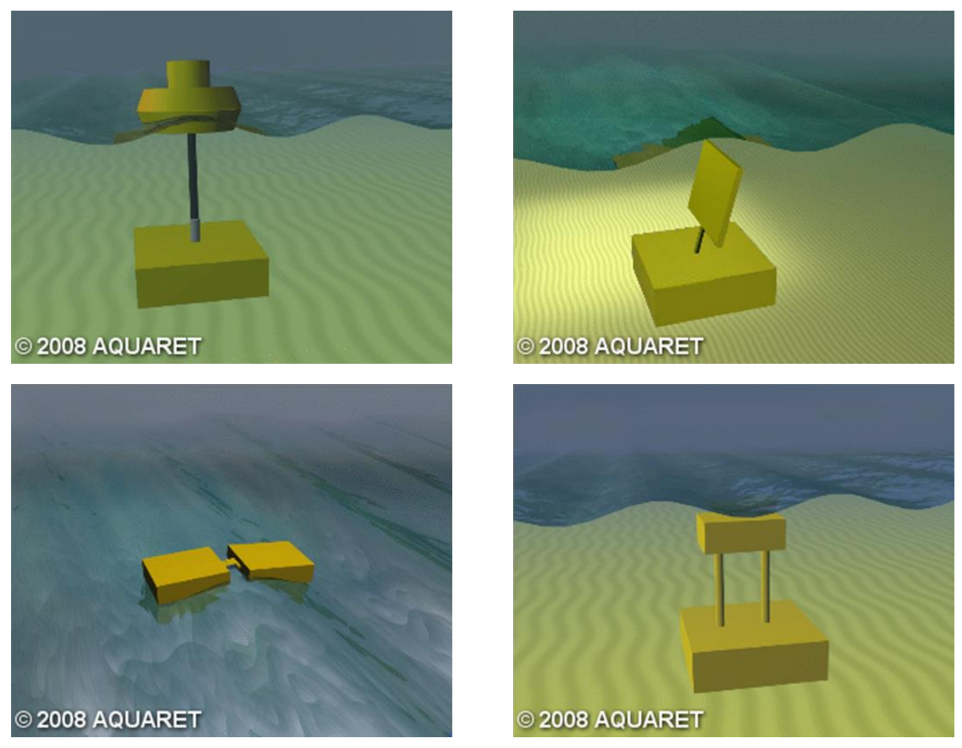
The Electro-Mechanical Generator (EMG)

The Electro-Mechanical Generator (EMG) is able to convert reciprocating **linear motion into electricity**. It consists of a recirculating **ballscrew** integrated with a rotational **permanent magnet generator**.

This architecture is already commercialized in actuators for the **aerospace, industrial** and **energy** sectors. It has a **long track record** of **high efficiency** and **reliability**.

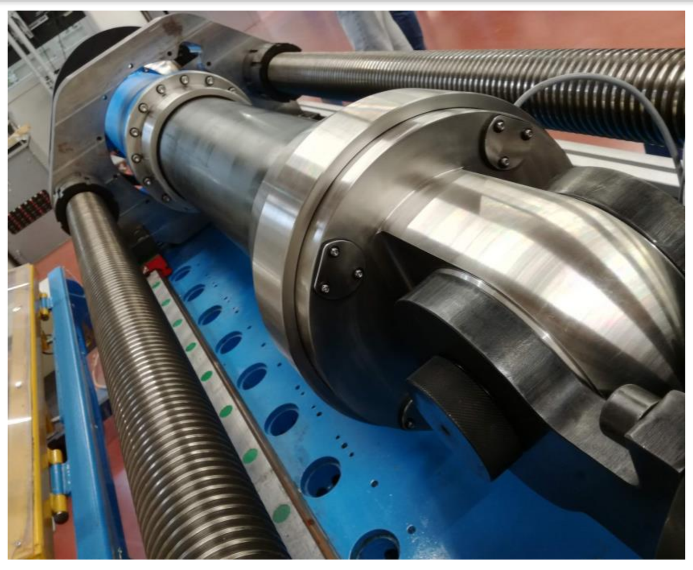
The EMG can be integrated straightforwardly into a number of WEC concepts: **attenuators**, **point absorbers**, **oscillating wave surge converters**, **pressure differential devices**.

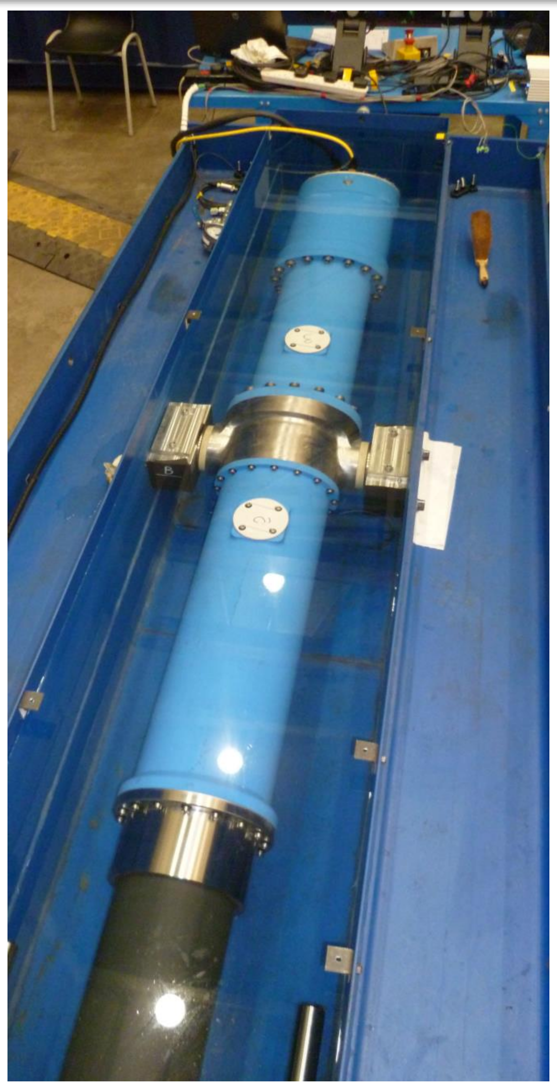


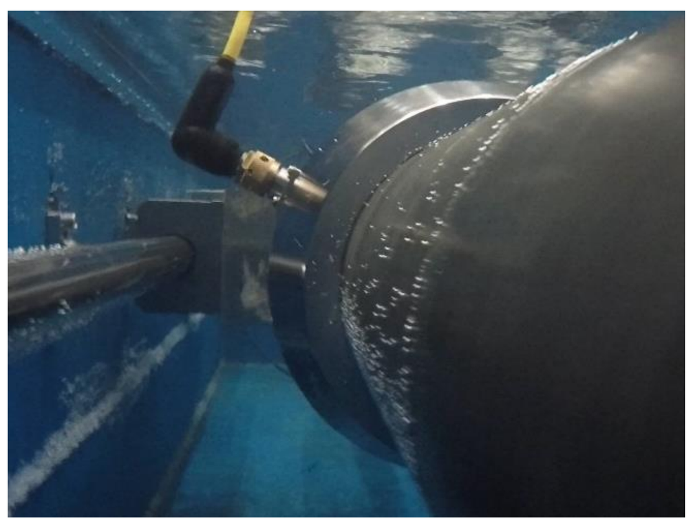


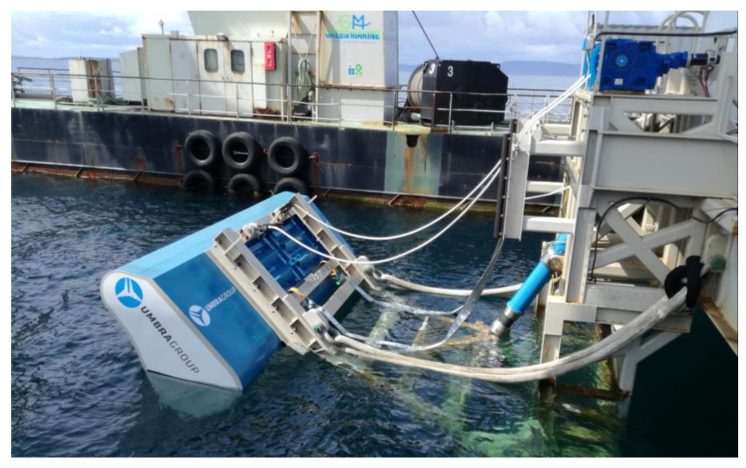
Stage 3 Project: Finalization of MS4 (Fabrication of EMG, PCM system and PPB) and MS5 (PTO Laboratory Tests)

EMG Specifications		
Peak axial load	160	kN
Peak axial speed	1335	mm/s
Total stroke	1060	mm
Peak mech. power	200	kW
Minimum pin-pin length	2500	mm
Diameter	235-317	mm
Mass	650	kg







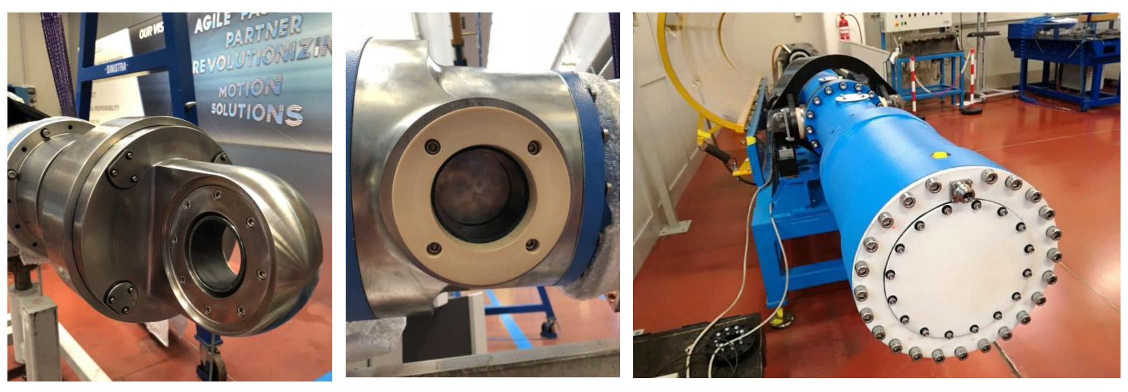


Stage 3 Project: Target Outcomes for the EMG

Target Outcome	Measurement	Project target	Project at the end
Affordability	Capital cost per unit of peak electrical power	800-1000 £/kW	**694 £/kW**
Performance	Average mechanical-to-electrical efficiency	65-85%	**70%**
Availability	MTBF	20y	**NO FAILURES**
Survivability	Load ratio	5	**10**
	Survivability in marine environment	12 weeks	**15 weeks**

Stage 3 Project: Timeline

- May 2017 — **Project kick-off**
- July 2017 — **MS2: System Specification Control Document**
- December 2017 — **MS3: Finalization of the WEC, PTO & CS Design**
- November 2018 — **MS4: Finalization of the WEC, PTO & CS Fabrication**
- December 2018 — **MS5: PTO Laboratory Tests Completed**
- May 2019 — **MS7: Techno-economical Evaluation**
- Aug. 2019 — **MS6: PTO Sea Tests Completed**
- Oct. 2019 — **MS8: Technology and Test Qualification**
- Dec. 2019 — **End of project**



EMG prototype
- Design for marine environment
- Fabrication at Umbra's facilities

TRL 5

Bench tests
- Submerged in synthetic sea water
- Hardware-in-the-loop configuration

TRL 6

Sea trials
- Installation on point-pivoted buoy
- Use of gantry barge for ease of access

TRL 7

energy technology partnership · GREEN MARINE · DOOSAN · HMS · The University of Edinburgh · JGC · SUPPLYDESIGN · Bureau Veritas · SEAPOWER scrl Consortium with University of Naples Federico II · UMBRAGROUP

Luca Castellini
Energy R&D and BD Manager
Engineering Dept.
UMBRAGROUP S.p.A.
Via V. Baldaccini, 1 - Z.I. Loc. Paciana
06034 Foligno, (PG) - Italy
Tel.: +39 0742 348 431
Mail: lcastellini@umbragroup.com

WES CREATE Stage 2
Concrete as a Technology Enabler

Introduction

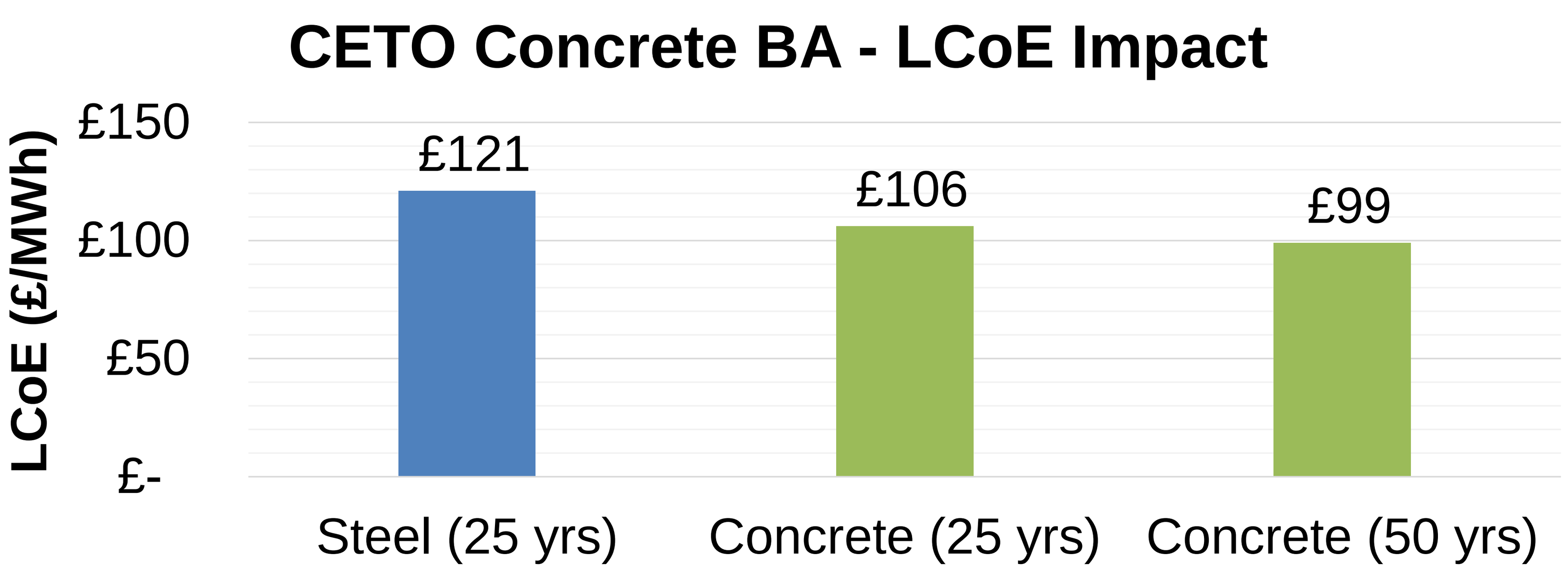
The CREATE project aims to demonstrate the potential of concrete to enable cost reduction in Wave Energy Converter (WEC) structures. Stage 1 involved a sector wide review and pre-Front End Engineering Design (FEED) of the WEC most suited to concrete construction. In Stage 2 the design was developed to FEED level, with detailed assessment and material testing to address key technical risks with broad applicability to the WEC sector.

Structural Design

The concrete design is based on the buoyant actuator (BA) for the Carnegie CETO 6 device. The Stage 1 concrete BA design was developed into a precast concrete solution during Stage 2, with a focus on high risk structural details including precast connections and tether attachment points.

Manufacturing Assessment & Costing

OPEX and CAPEX have been considered to derive the Levelised Cost of Energy (LCoE) to illustrate the benefit of concrete over steel. Manufacturing costs have been independently estimated by BAM Infrastructure Advisory, and a technical roadmap to serial production developed.

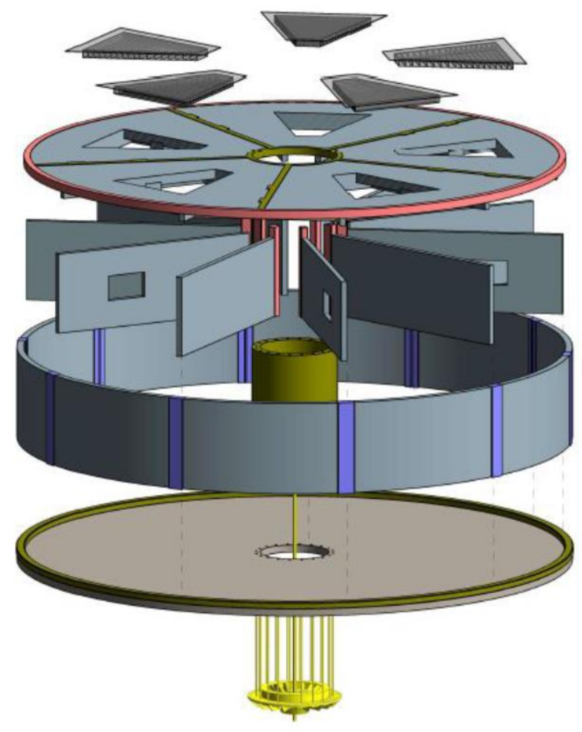


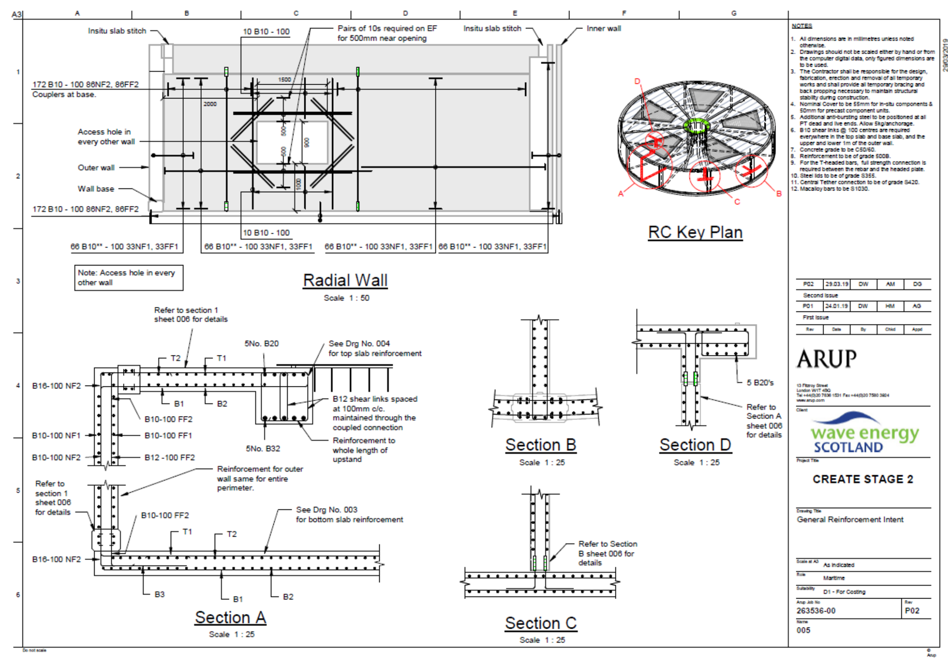
Risk Reduction Testing

Stage 1 highlighted water-tightness of precast connections under cyclic loading as a key technical risk. The interleaved T-headed bar joint proposed for the design is an innovative type of precast connection and was therefore selected for testing. Both detailed numerical and full scale physical tests were undertaken and showed good correlation in results. The tests demonstrated the serviceability performance of precast connections for an example WEC application, with broad applicability to the sector.

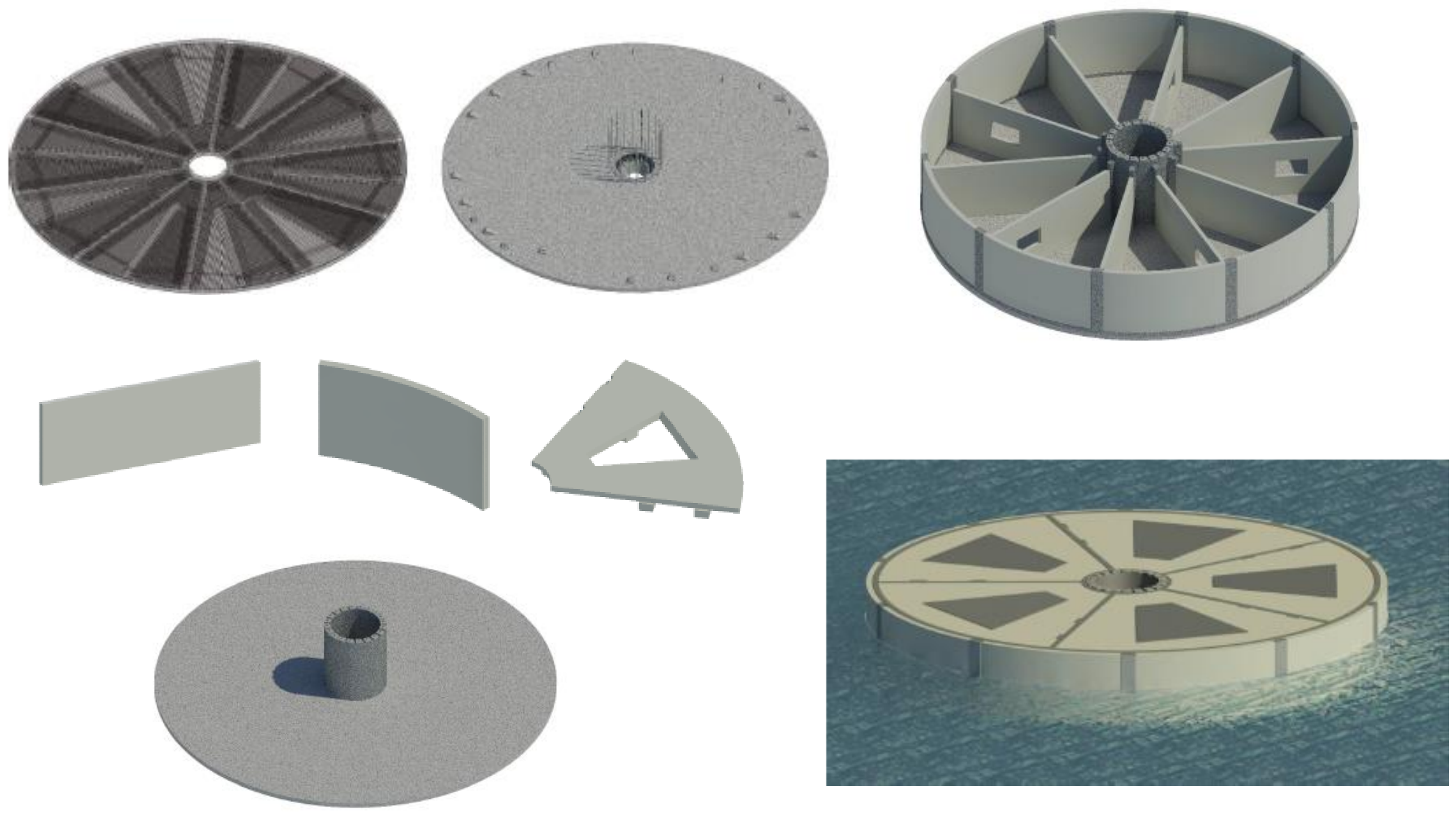
A comprehensive risk assessment and mitigation strategy will inform the scope of work for *CREATE Stage 3: Manufacturing Demonstration (anticipated 2019/2020).*

Structural Design

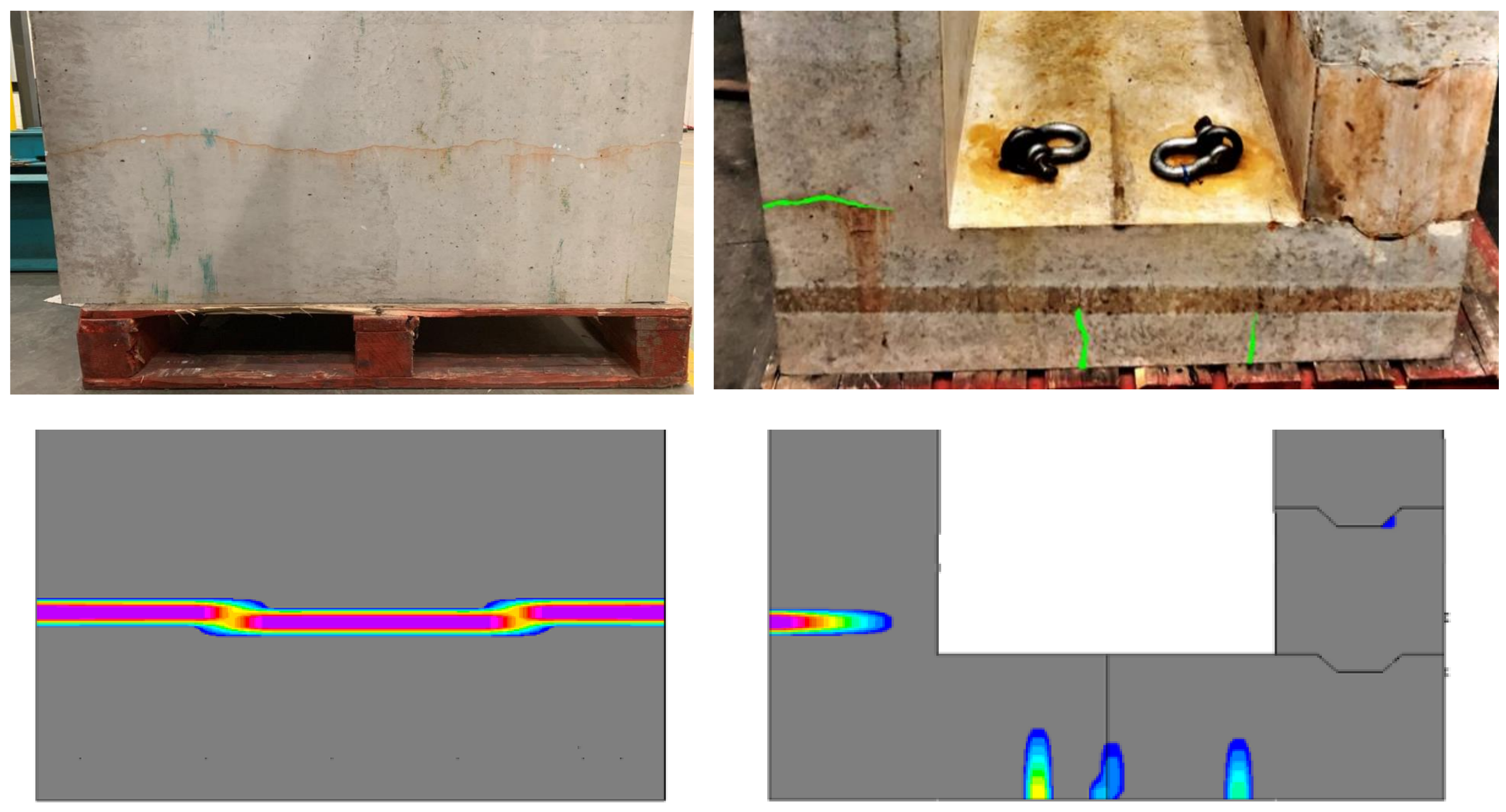




Manufacturing Assessment



Risk Reduction Testing



Subcontractors

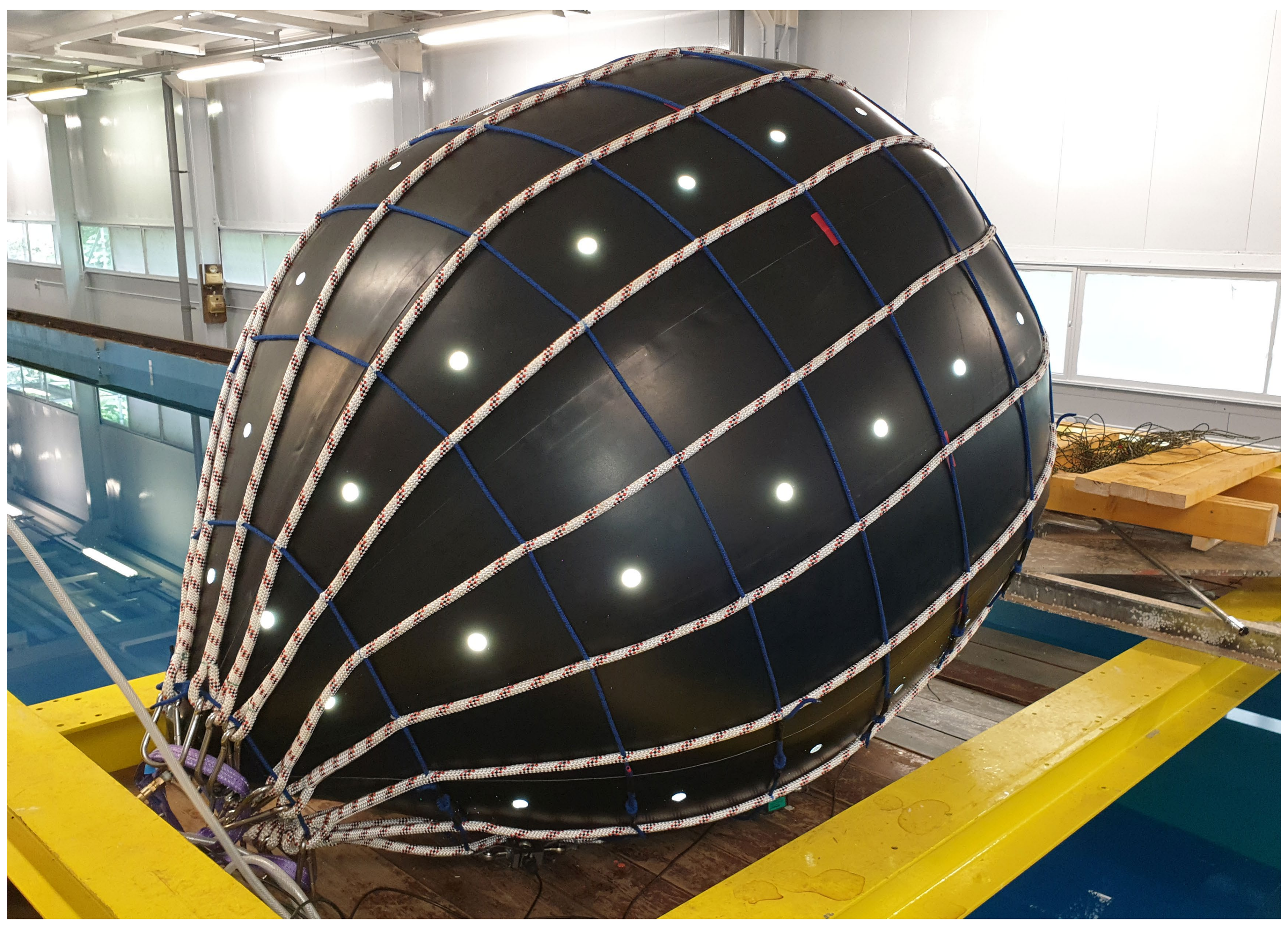
1. Cruz Atcheson Consulting Engineers
2. Carnegie Clean Energy
3. Doosan Babcock
4. The Concrete Centre/British Precast
5. BAM Infrastructure Advisory
6. Mocean Energy

ARUP DOOSAN bam Infrastructure Advisory mocean energy cruz atcheson CONSULTING ENGINEERS Carnegie wave energy mpa The Concrete Centre

George Walker
Karoline Lende
george-a.walker@arup.com
karoline.lende@arup.com

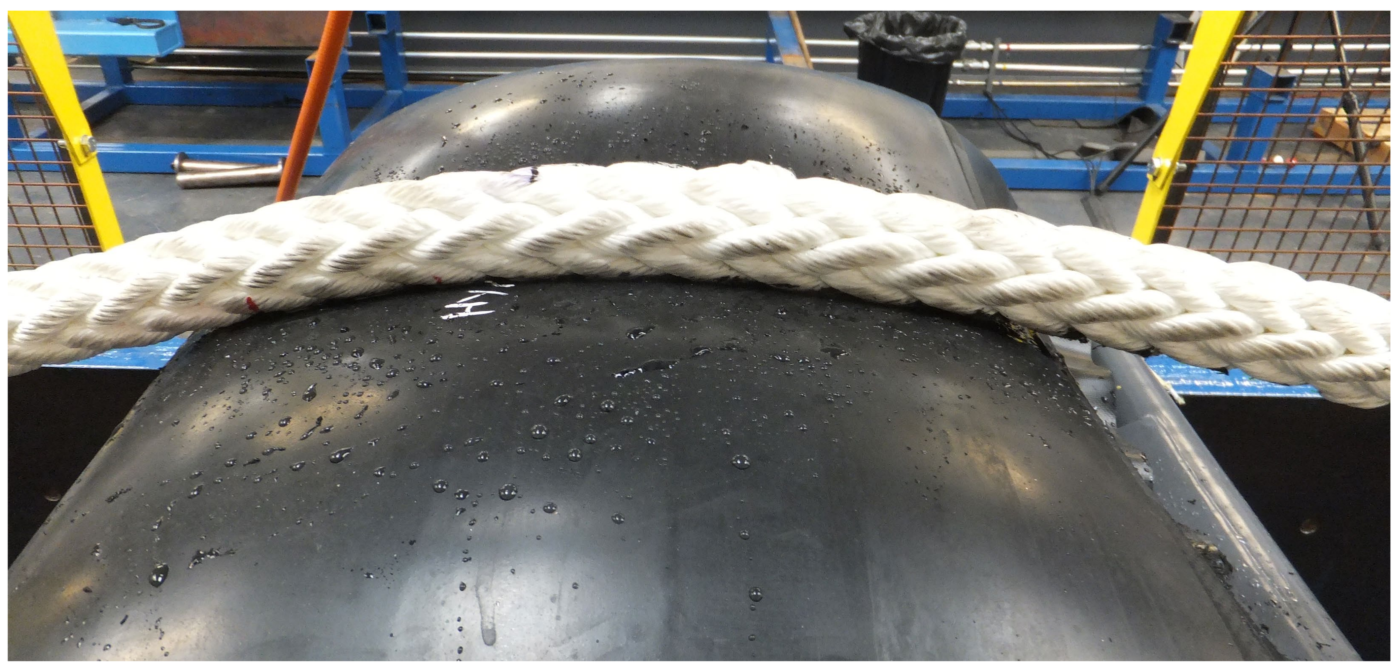
Fourth Annual Conference
#WESAC19

Netbuoy Stage 2
Structural Material & Manufacturing Processes

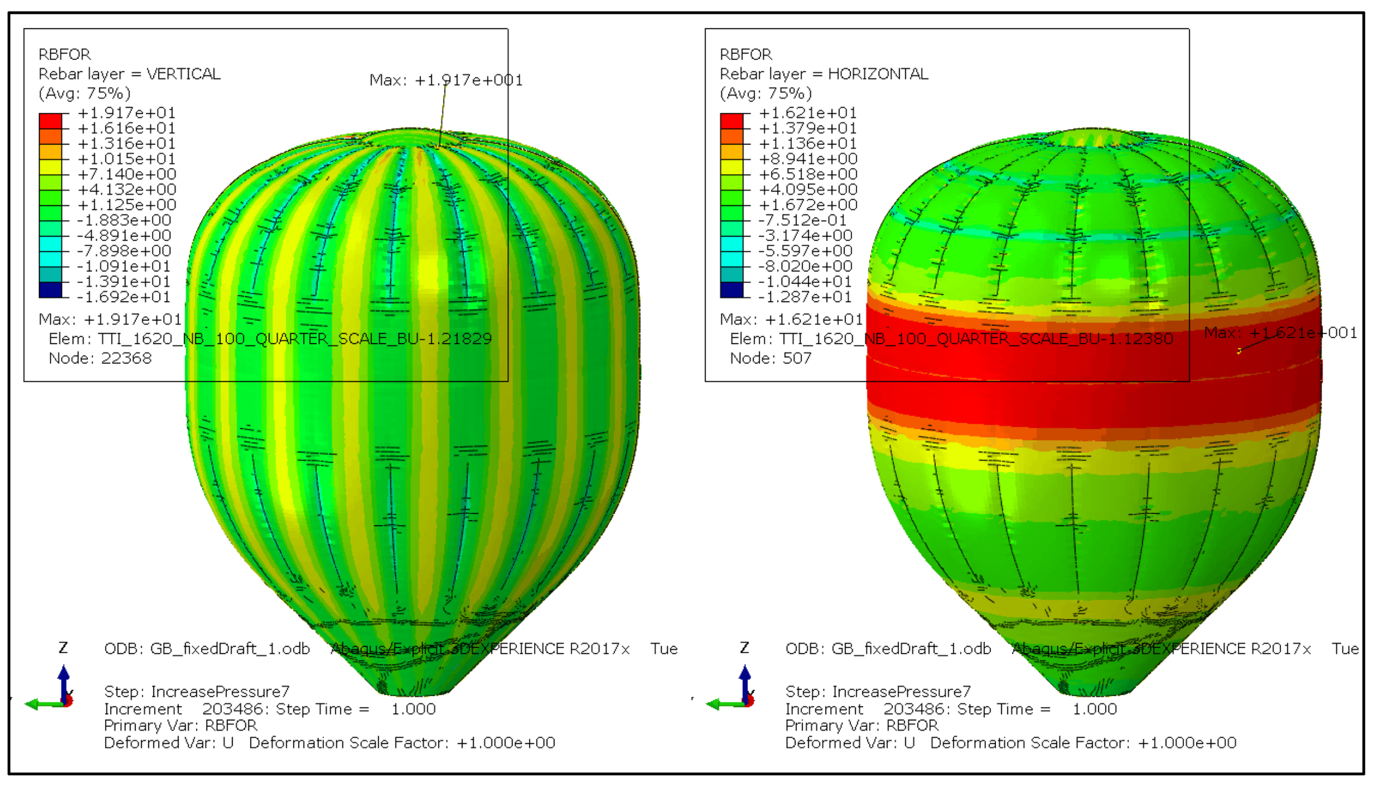


¼ scale tank model

15th scale survival tests



Full-scale rope abrasion tests on inflated pillows (5 candidate membranes)



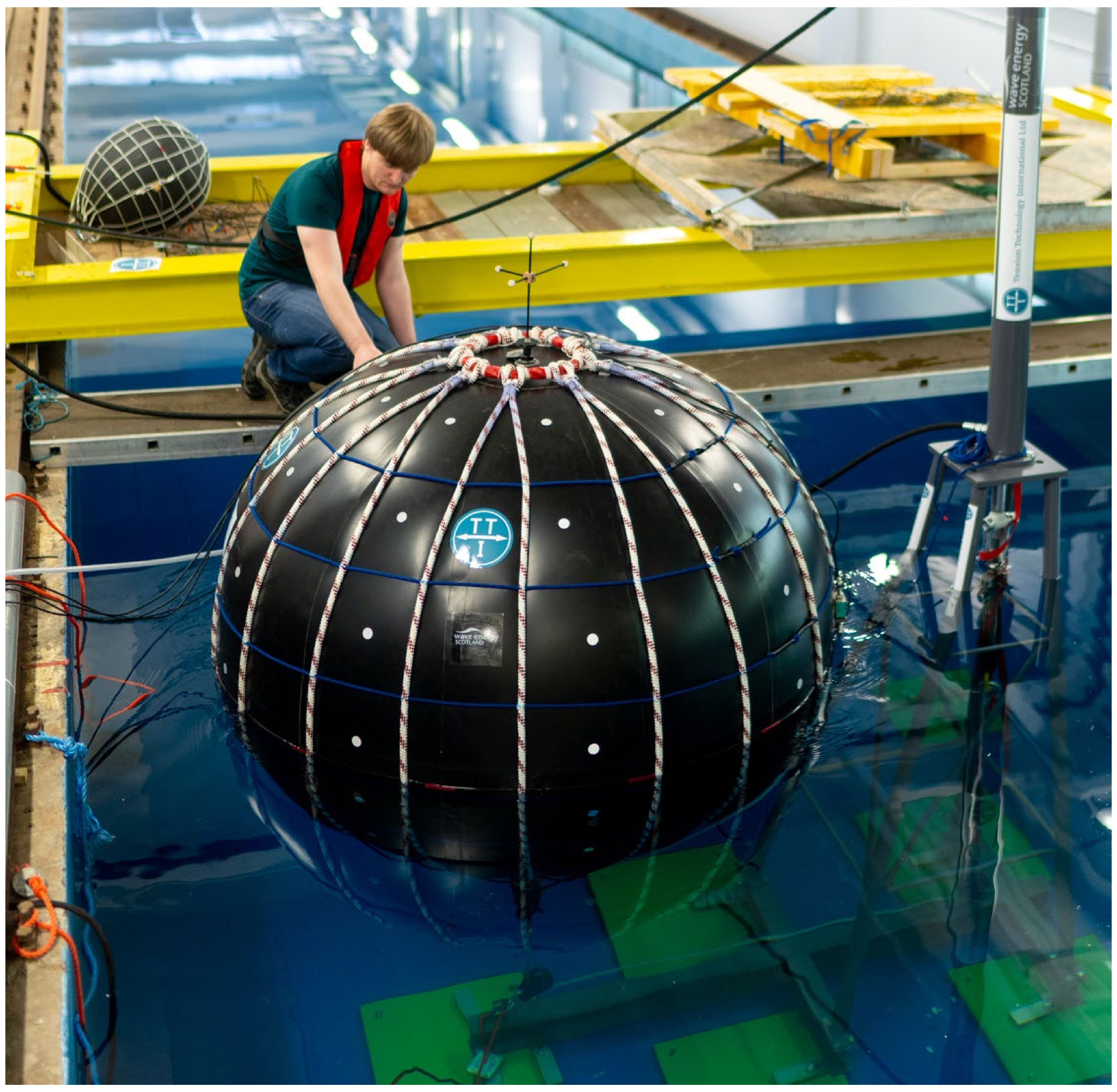
FEA models correlated with physical tests

The Concept:

The NetBuoy concept aims to significantly reduce the construction and installation cost of wave energy converter prime movers. A pressurised reinforced elastomer buoy is restrained within a rope net. The net provides the load-path between compliant buoy and PTO or structure. The inflatable technology provides favourable load shedding and survivability characteristics. The system as a whole can be inflated at the deployment site, significantly reducing the space requirement for transportation from point of manufacture. Partial inflation at point of hook-up means any pull down loads can be reduced. For these reasons lower cost vessels can be used and towing to site minimised. The NetBuoy concept has been developed around a heaving point absorber which can be attached to linear power take off and tether to the seabed using anchor, however Stage 1 assessment has shown this technology to be applicable to many WEC types.

The Project:

Stage1 demonstrated the excellent cost-benefit and technical viability of the NetBuoy compared to steel based equivalent buoys. A comprehensive landscaping and design engineering study was conducted. Manufacturability and ease of installability was used to inform the Stage 1 economic model. A key aim of Stage 2 was to deliver the qualification tests and mitigate technology risk via a systems engineering approach as outlined in Stage 1. TTI continued to adhere to DNVGL-RP-A203 recommended practice for the qualification of novel technology. Stage 2 of the project involved scaled full-system manufacture and wet testing together with full-scale sub-system and component testing. Data acquired from these tests was used to correlate and update numerical and FEA models developed under Stage 1. Design tools, manufacturing and installation know-how was then used to optimise the design and update the levelised cost of energy and commercialisation. Examples of completed qualification tests and modelling conducted under Stage 2 are presented here.



¼ scale tank tests and pull-down rig

If you are a WEC developer or supplier who has interest in the potential of this technology, please contact Tom Mackay or Ben Yeats below:

yeats@tensiontech.com
mackay@tensiontech.com
www.tensiontech.com

CEORL

Cost of Energy Optimised by Reinforcement Learning

Introduction

The CEORL project applies reinforcement learning (RL) to control of wave energy converters. The RL rewards reflect our aim: reduction in cost of energy.

In Stage 3, we aim to demonstrate, in Hardware-in-the-Loop and tank tests:

- Increased mean power without increase in peak loads.
- Decreased peak loads without decrease in mean power.

Method

- RL learnt variable-coefficient policies (Fig. 1)
- Baseline: fixed-coefficient PI control
- RL and baseline policies: specific to one spectrum
- High energy rewarded; large motions penalised

Stage 2 results

- Early results indicated 10x more mean power.
- Penalty added to large control forces F_c (Fig. 2)

Sense check

- Theoretical limits of heave results checked (Fig. 3)

Subcontractors

Pelagic Innovation Ltd: Donald Naylor
Power Enable Solutions Ltd: Richard Crozier,
Marine Systems Modelling: Joseph van t' Hoff,
The University of Edinburgh: David Forehand,
Wave Conundrums Consulting: Alexandra Price
Aquaharmonics: Max Ginsburg and Alex Hagmüller,
David Pizer
Quoceant: Ross Henderson

Figure 1

Geometry:
radius = 1.5 m
draft = 5 m

Spectrum:
H_s = 2.75 m
T_e = 8.5 s

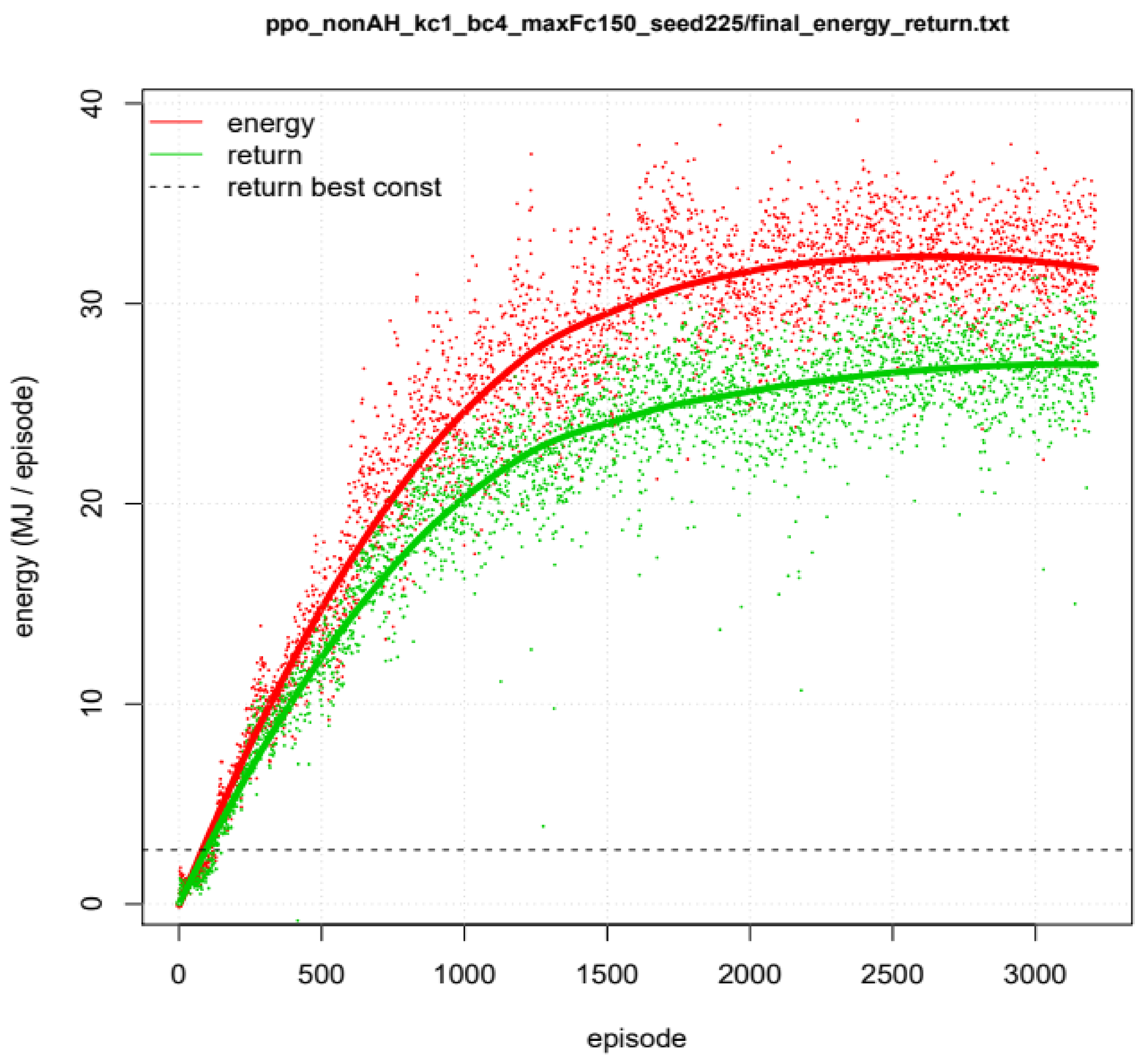


Figure 2

Geometry and spectrum as above.

Heave and surge motion.

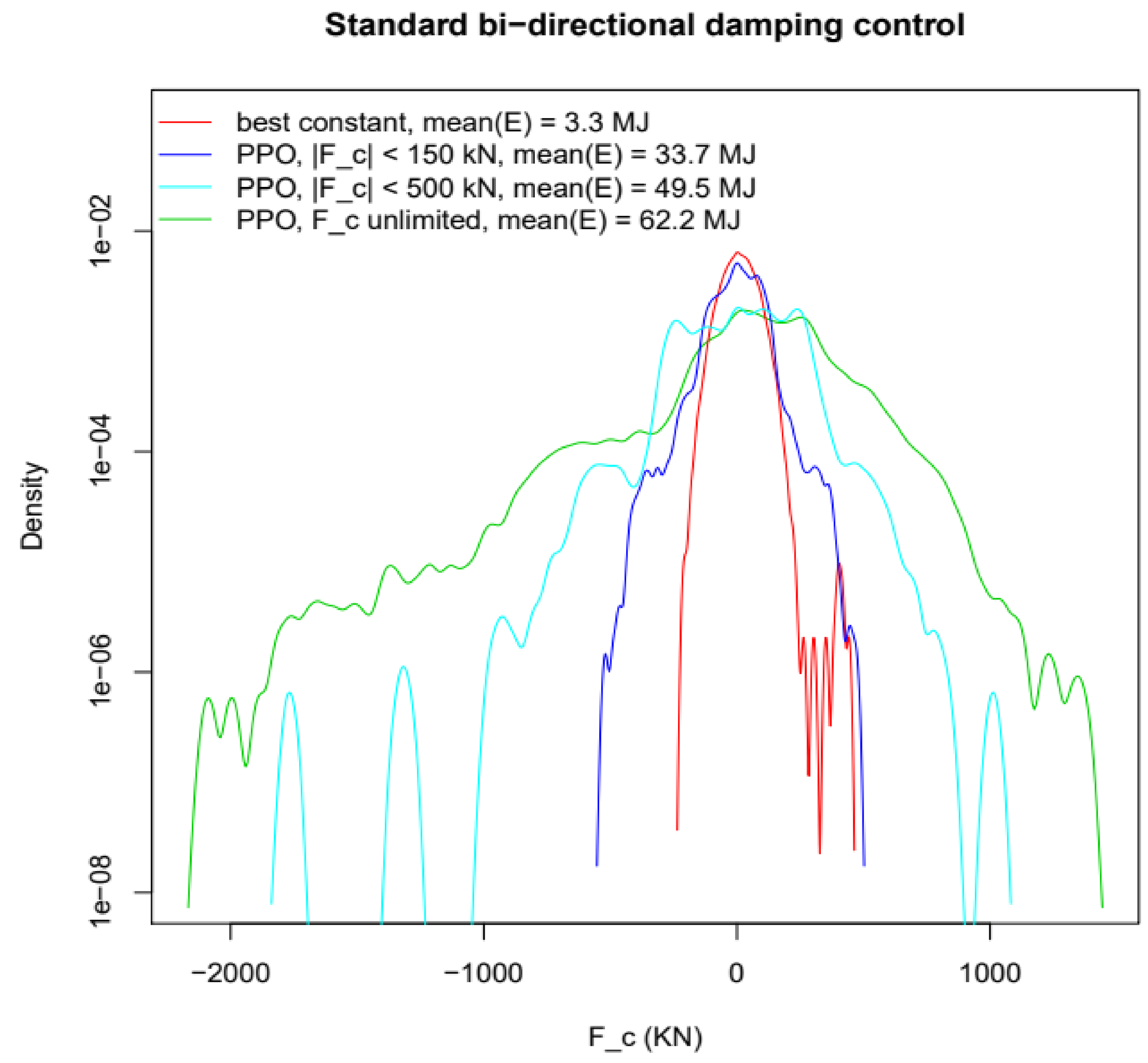
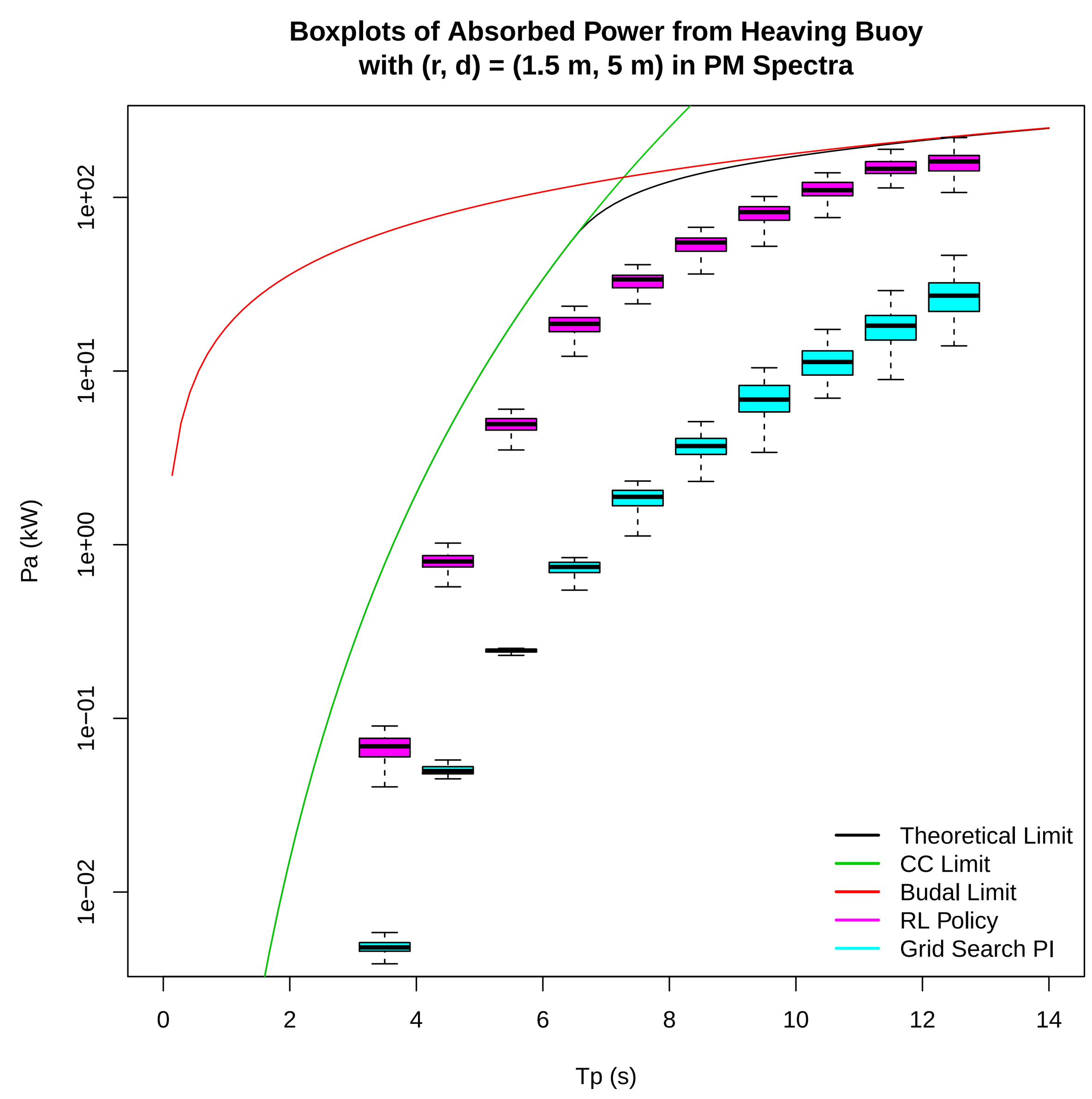


Figure 3

Geometry as above.

Heave motion only.



MaxSim
Wave Conundrums Consulting
AquaHarmonics
THE UNIVERSITY of EDINBURGH
REOPTIMIZE SYSTEMS

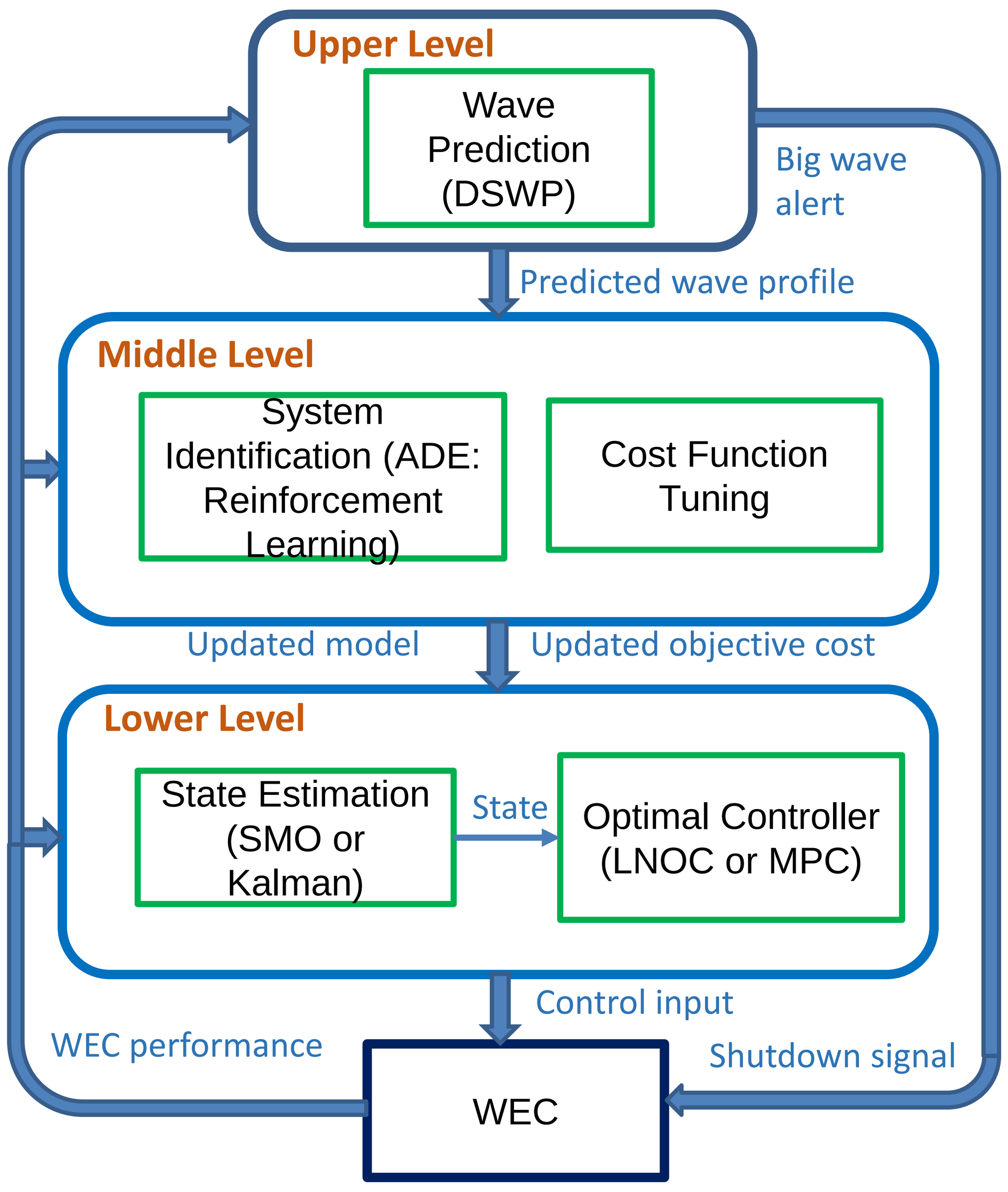
Contact:
paulstansell@gmail.com

Physical demonstration of the Adaptive Hierarchical Model Predictive Control (AHMPC) for Wave Energy Converters

Introduction

Our Stage 3 project of WES control programme aims to provide experimental validation for the AHMPC framework of an attenuator wave energy converter using FlowWave tank facilites.

Control Framework and numerical results



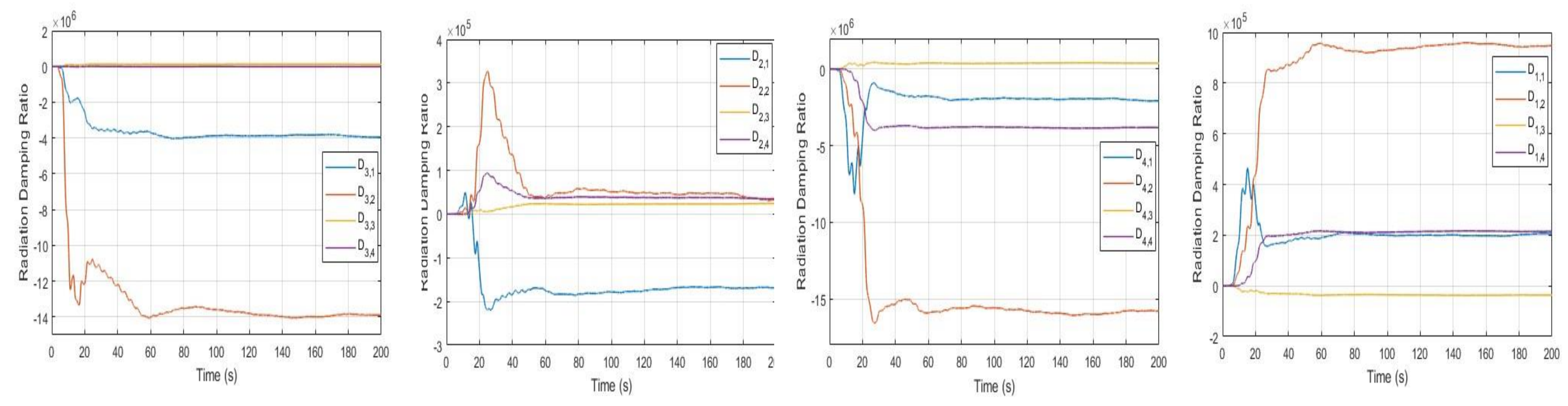
Main benefits:

1. *Maximum energy output*
2. *Safe operation*
3. *Robustness*
4. *Survivability*
5. *Universally applicable*

Enabling technologies:

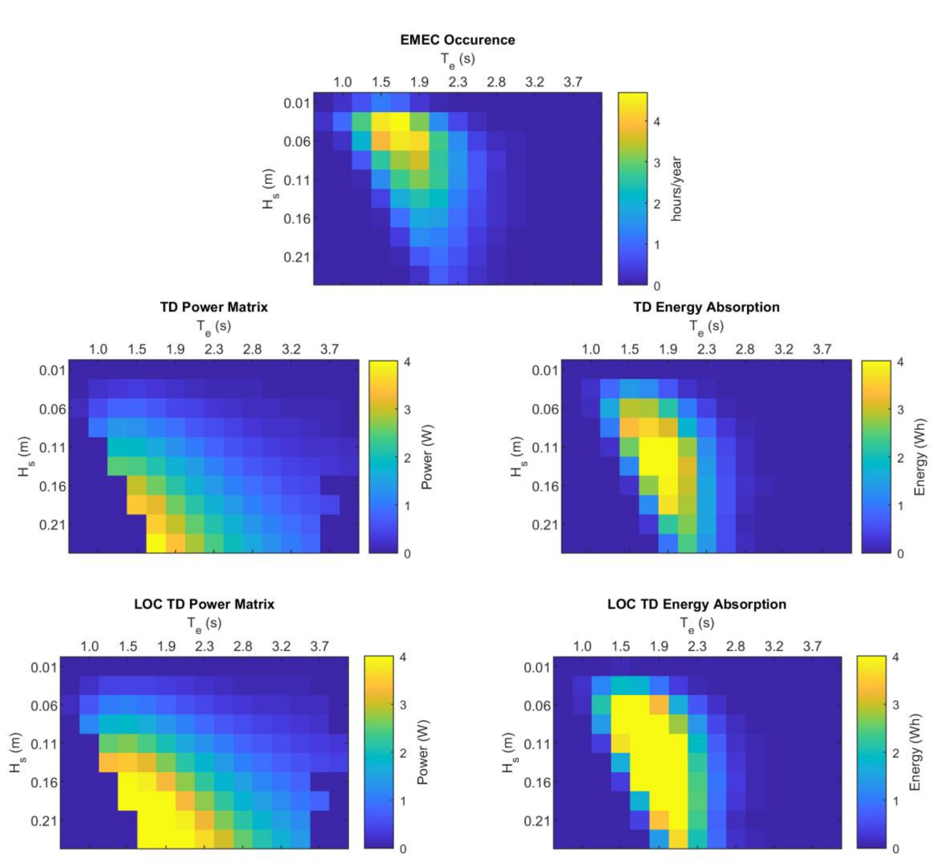
- *Deterministic Sea Wave Prediction*
- *Linear optimal control*
- *Model Predictive Control*
- *Reinforcement learning*
- *Sliding mode observer*

Middle layer dynamics estimator

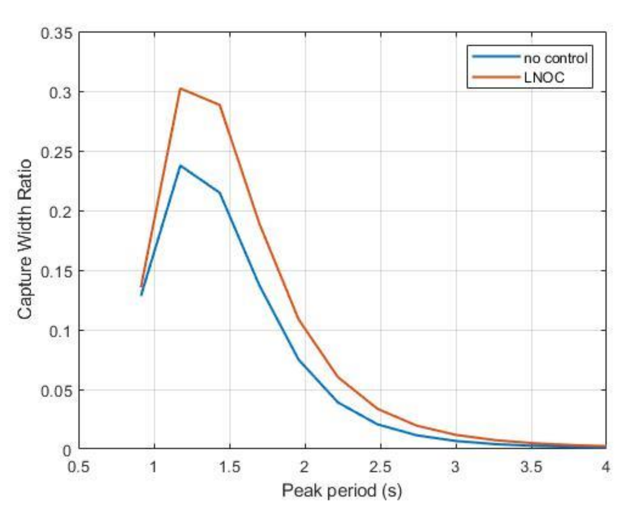


Key dynamics parameters identified by Adaptive Neural Networks converge to accurate values very rapidly.

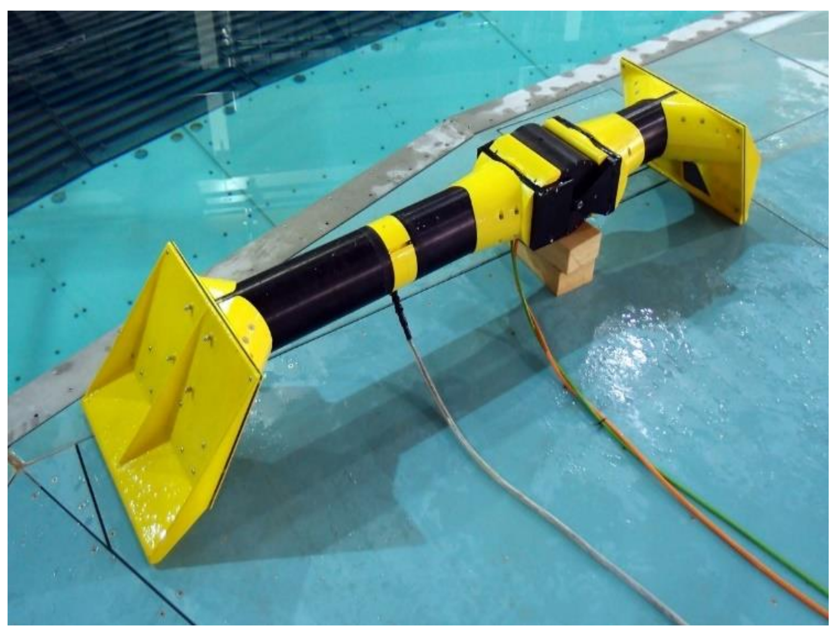
Lower layer control performance (LNOC)



Capture width ratio improvement:



De-risking and tank testing plan



Mocean M100 WEC:

- *1/20th scale WEC model*
- *Asymmetric design for higher capture width ratio*
- *Multi-mode attenuator with complicated dynamics*
- *Experimentally Validated numerical model for controller design*

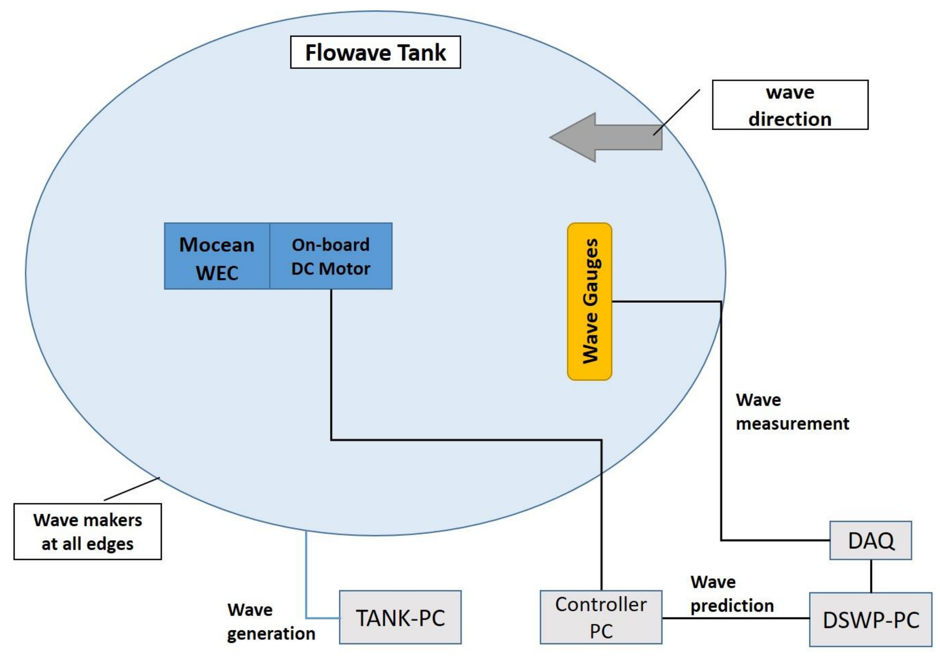
Chosen facility for tank testing: FloWave Ocean Energy Research Facility

Kollmorgen AKM motor

B&R X20 controller

Hardware-in-the-loop (HIL) test:

1. *HIL rig to be built up to test real-time implementation of control algorithms.*
2. *Kollmorgen DC motor acting as Power Take-off (PTO) unit will be embed at WEC hinge*
2. *B&R high specification controller to execute control algorithms and provide signal interfaces*



Demonstrative diagram of tank testing hardware setup

Project schedule:

- *Now - 01/2020*
  Numerical simulation and validation.
- *01/2020 – 04/2020*
  De-risking HIL test
- *07/2020*
  Tank testing phase 1
- *10/2020*
  Tank testing phase 2

Subcontractors

1.Mocean Ltd.

Dedicated in attenuator type WEC design, provide numerical and physical WEC model validation.

2.University of Exeter

Expertise in ocean wave study and prediction, technical support for upper layer of control framework.

Project leader: Dr. Guang Li (g.li@qmul.ac.uk)