WES Annual Conference 2018

Project Progress Updates

File Contents

WES Annual Conference 2018

Project Progress Updates: Control Systems, Stage 2

File Contents

- MaxSim Ltd – Cost of Energy Optimisation by Reinforcement Learning [4 pages]
- Queen Mary University – Adaptive Hierarchical Model Predictive Control of Wave Energy Converters [12 pages]
- Wood – IMPACT – Integrated Marine Point Absorber Control Tool [8 pages]

Wave Energy Scotland Annual Conference, Elevator Pitches, 6th December 2018

CEORL – Cost of Energy Optimised by Reinforcement Learning – Control Systems, Stage 2

Max Carcas, Caelulum Ltd

CEORL

Contributors:
Paul Stansell, MaxSim
Richard Crozier, Power Enable Solutions
Joseph van t' Hoff, Marine Systems Modelling
David Forehand, The University of Edinburgh
Alexandra Price, Wave Conundrums Consulting
Max Ginsburg and Alex Hagmüller, Aquaharmonics
Max Carcas, Caelulum
David Pizer
Chris Retzler, Mocean Energy
Jørgen Hals Todalshaug, CorPower Ocean
Ross Henderson, Quoceant

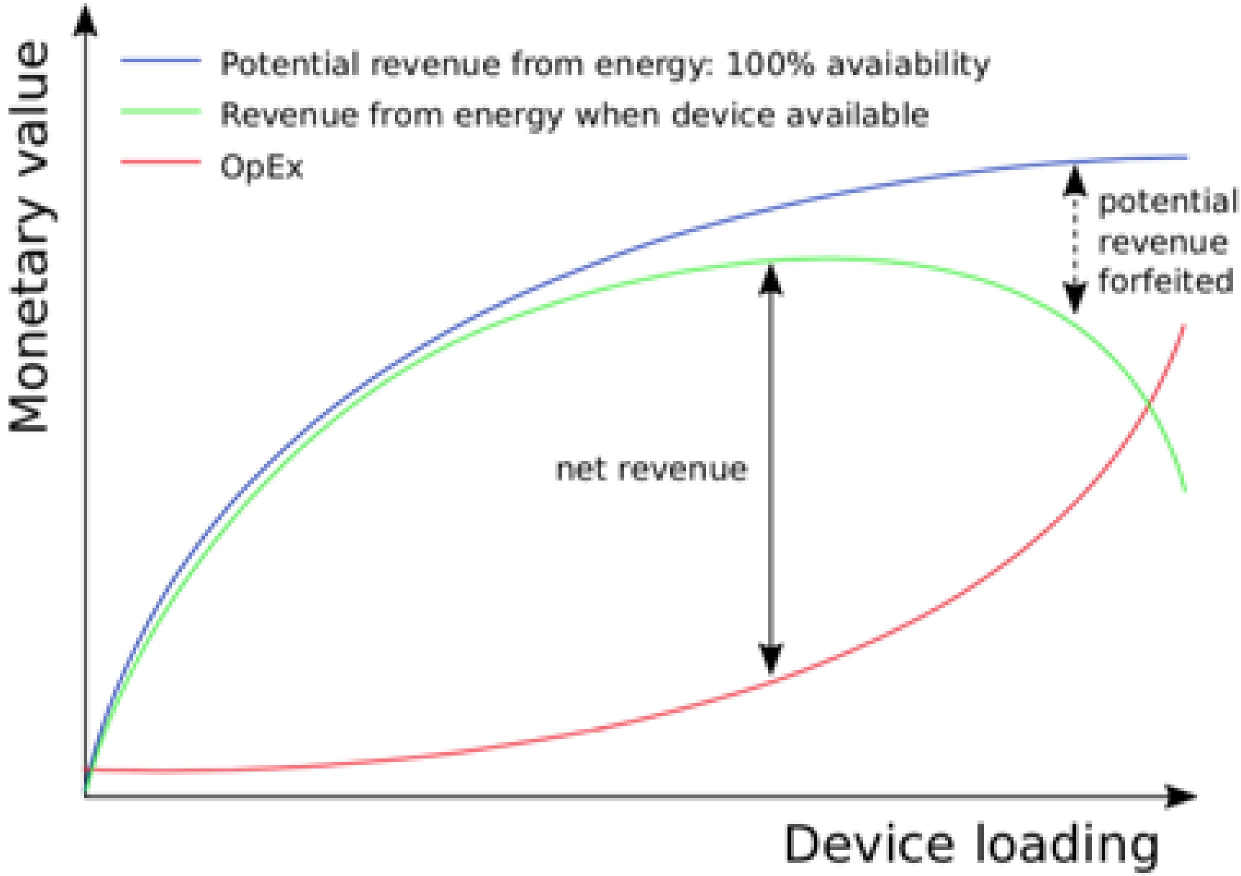
AquaHarmonics MaxSim

THE UNIVERSITY of EDINBURGH CAELULUM

wave energy SCOTLAND

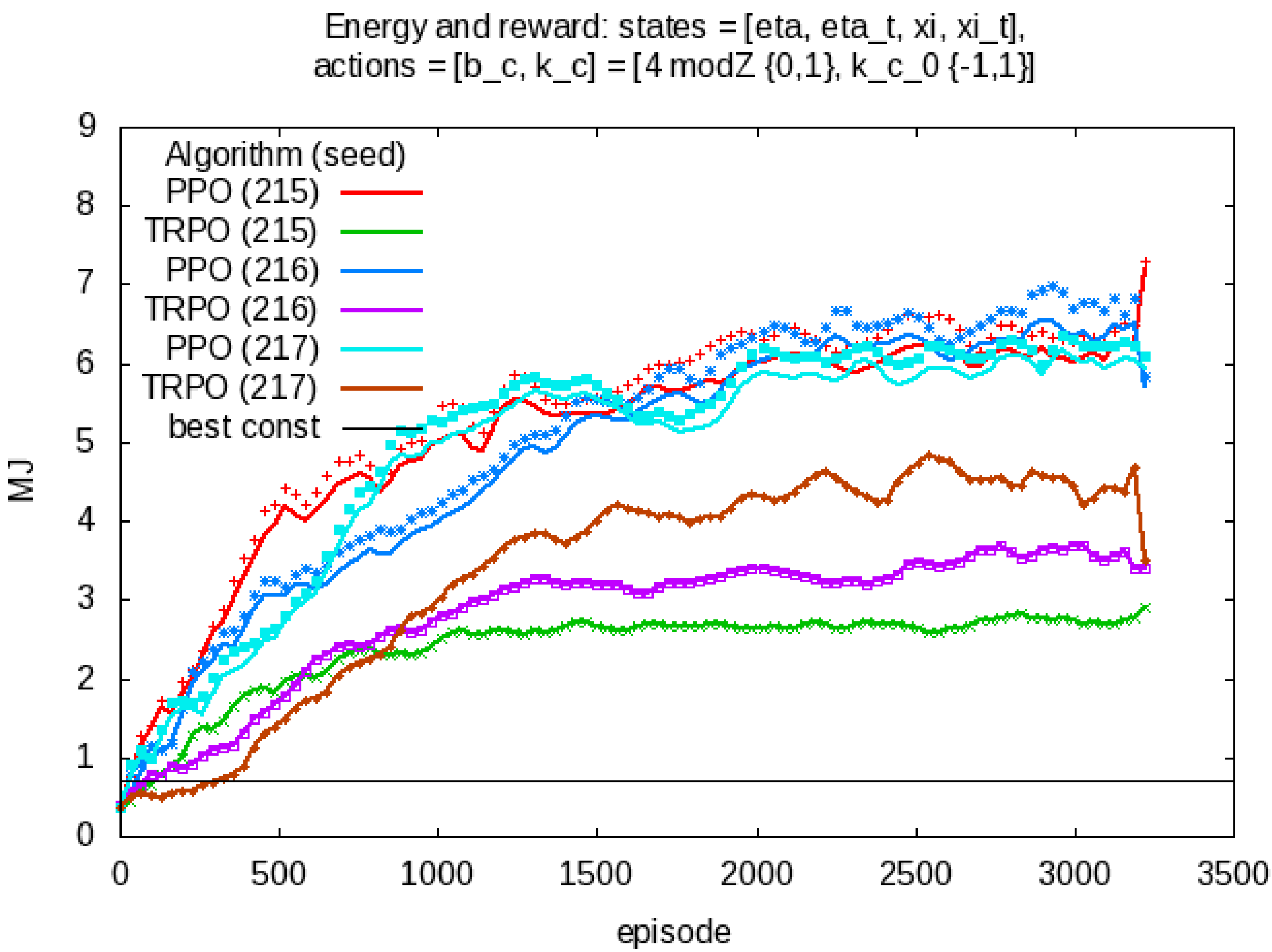
HIE Highlands and Islands Enterprise
Iomairt na Gàidhealtachd 's nan Eilean

Project Aim: Minimise LCOE



RL convergence

(simple model)



CEORL– CS Stage 2

Project Summary

- Control policy–Reinforcement Learning
- All controllable aspects:
  - PTO load (impedance, limits, etc.)
  - Device specific: mooring pretention, generator, etc.
- For this WES project: case-study partner is AquaHarmonics

Challenges

- How to express LCOE (long timescale) as a reward (short timescale)
- Transferability of policies between simulations and physical devices
- Stability of controller

Technical product or integration offering

- Wave-by-wave vs sea-state control:
  - Best use of load/stroke range
  - Timescale - wave groups & tidal interaction
- Pre-trained on a model
- Customised on physical device
- Uses only standard on-board sensor data
- Goal: minimise LCOE vs maximise power

Skills expertise or technology required

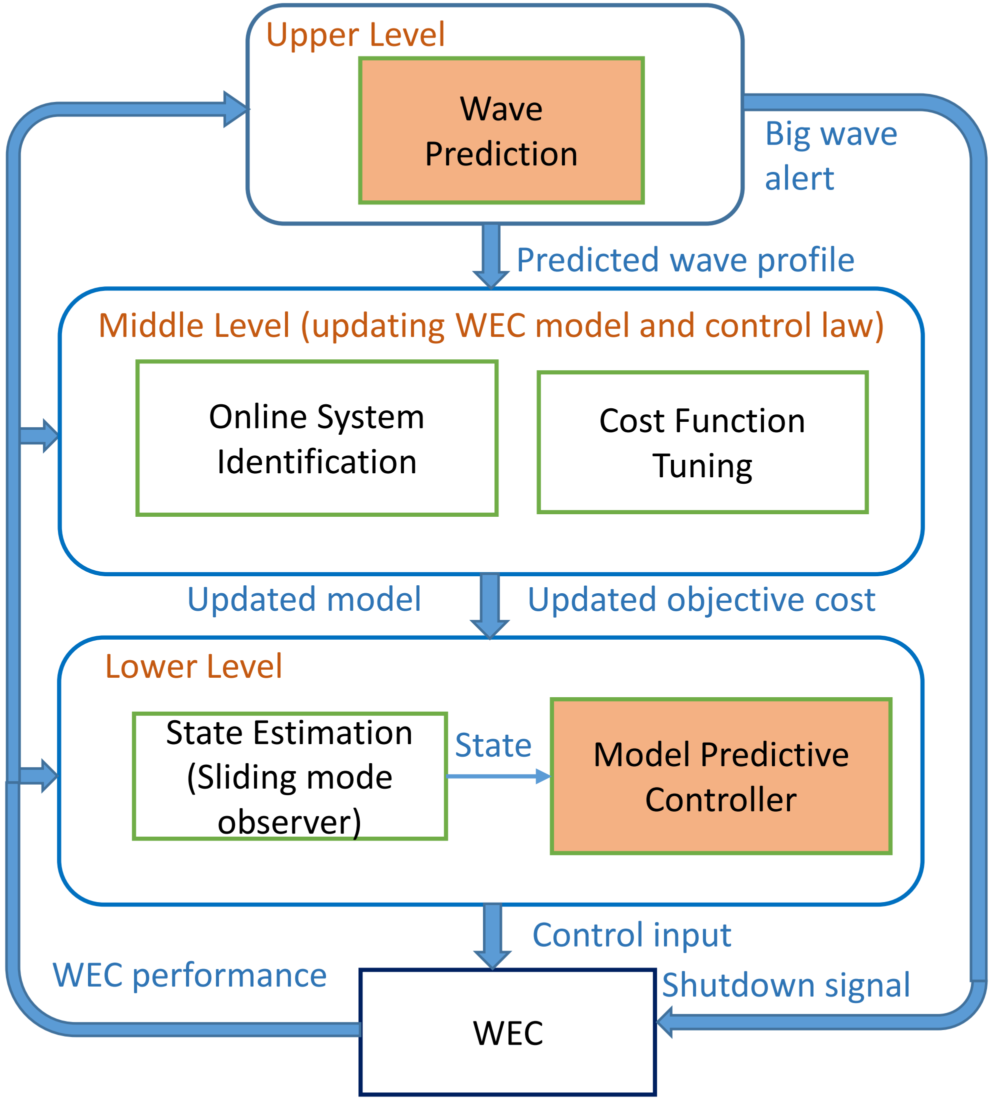
- For Stage 3 of WES Control call:
  - WEC developers - advice on specifications
  - PTO developers - advice on specifications
  - Space for hardware-in-the-loop tests
  - Tank for validation trials
  - Standard supervisory controller
- After WES programme:
  - WEC developers - case studies

Adaptive Hierarchical Model Predictive Control of Wave Energy Converters

STAGE 2 Control System Project of Wave Energy Scotland

Queen Mary University of London
Mocean Energy Ltd
University of Exeter
06/Dec/2018

The proposed control framework

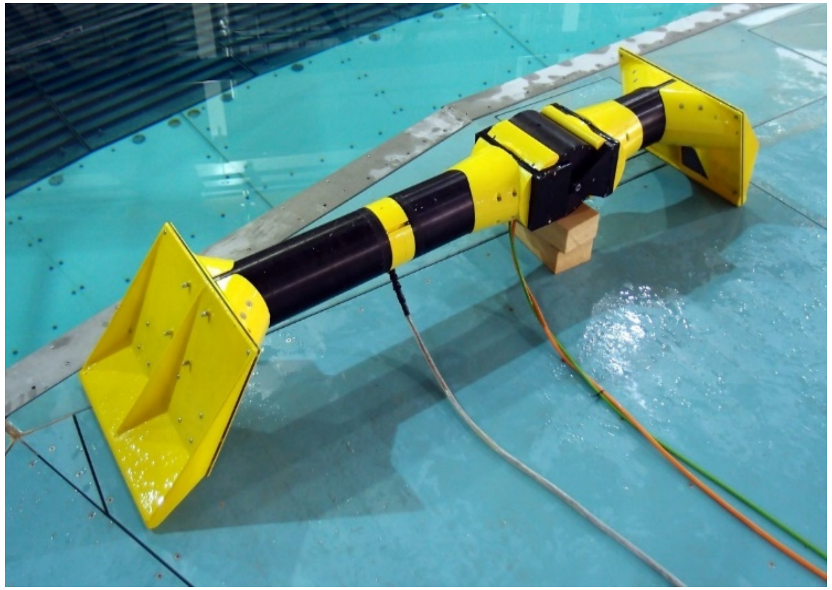


We aim to develop a hierarchical control framework to

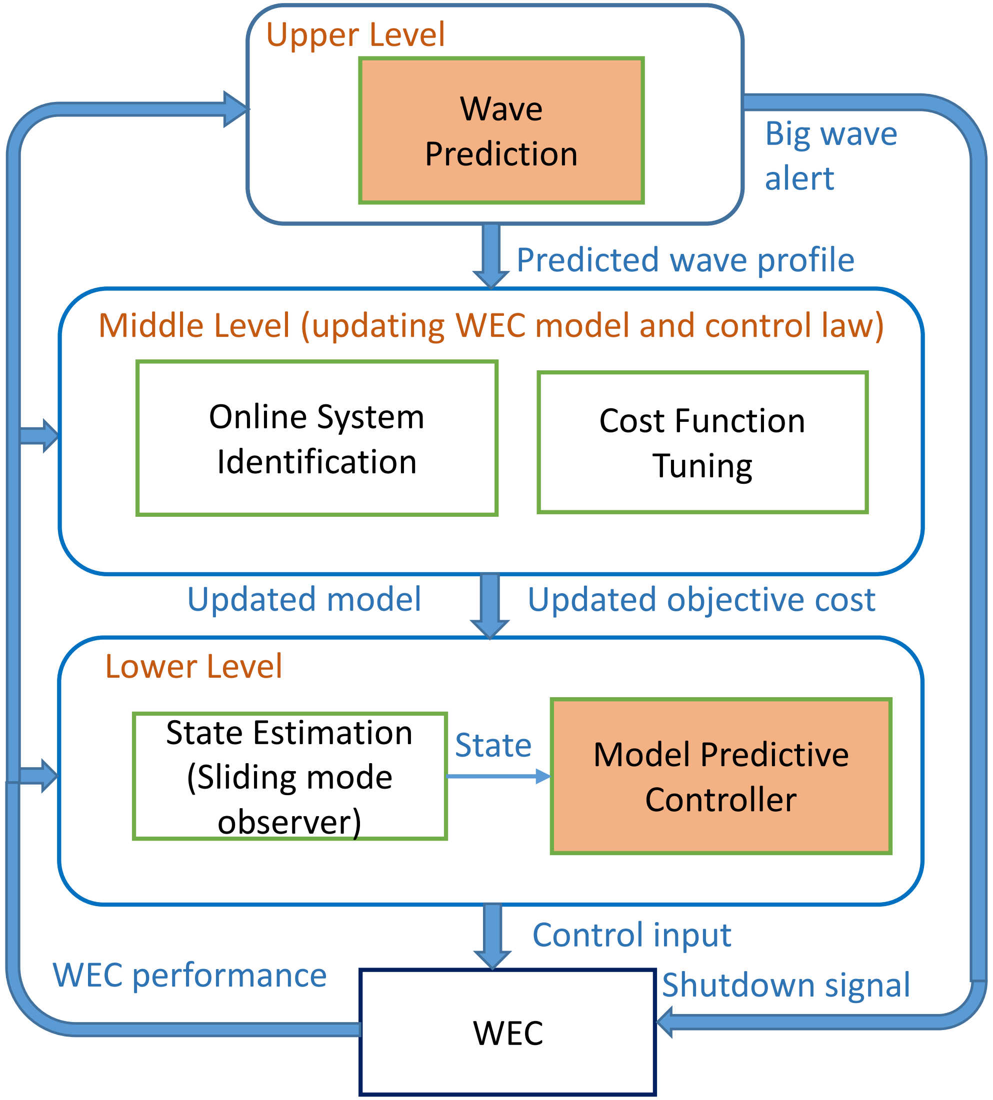
- maximise the energy conversion efficiency of a single WEC, and
- guarantee safe operation in different sea states.

The Device for Demonstration

- We are using the device developed by Mocean Energy Ltd.
- Attenuator type of device with two-floats and multi-motion.
- More complicated dynamics compared to the single-motion and single float device, e.g. point absorber.
- Thus modelling and control are more challenging!



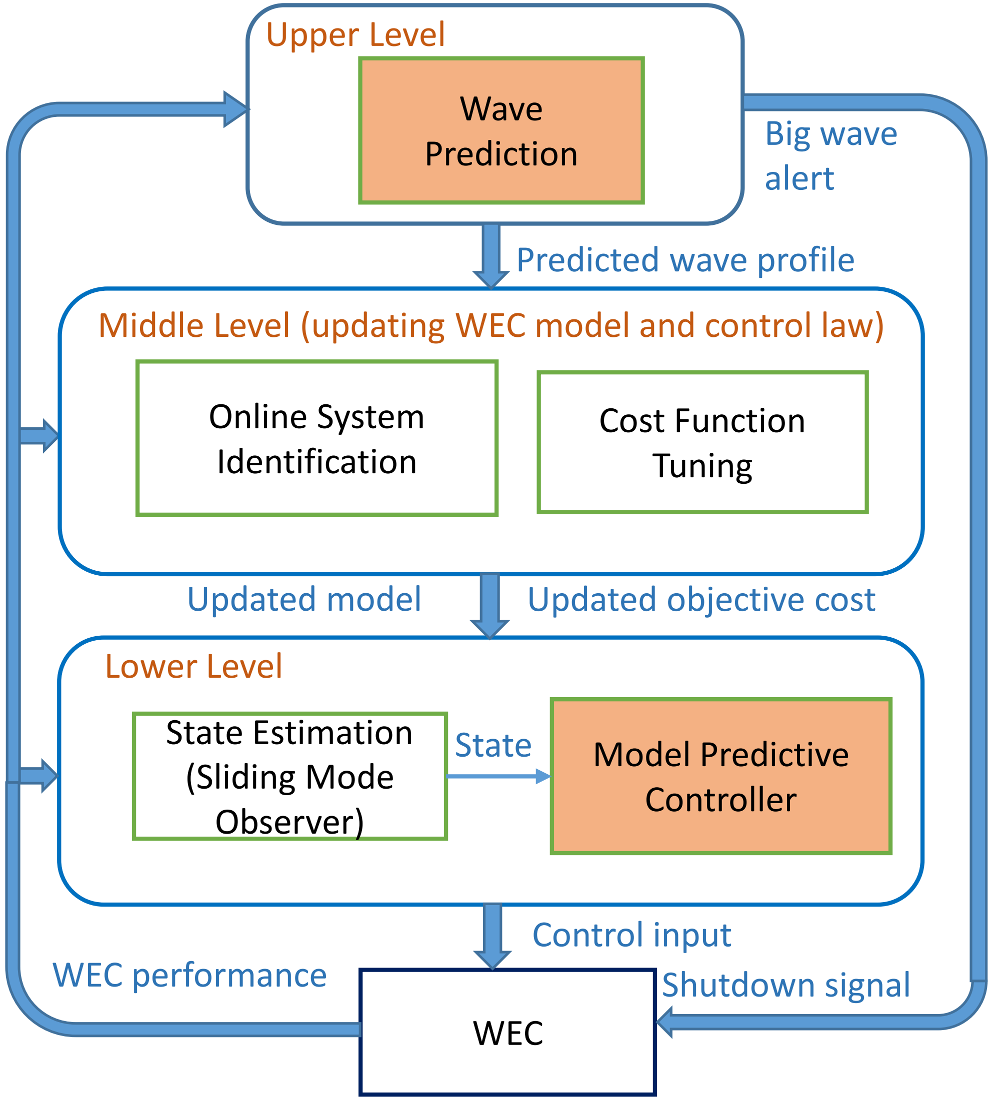
The proposed control framework



<u>How it works:</u>

- ***Upper level – wave prediction***
  1. Quiescent Period Wave Prediction technique to send detrimental wave alert to shut down WEC.
  2. Deterministic Sea Wave Prediction to predict wave profile.

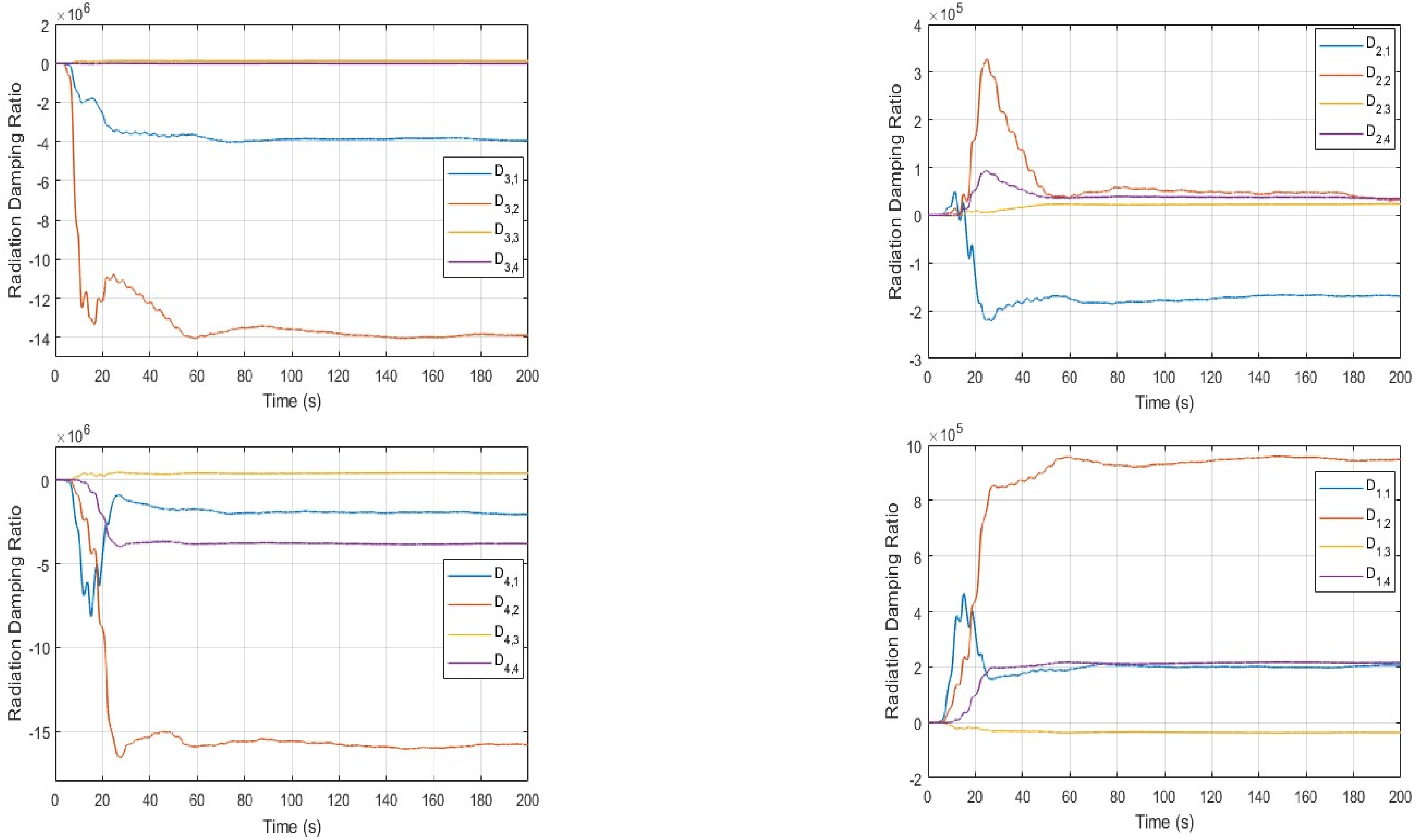
The proposed control framework



How it works:

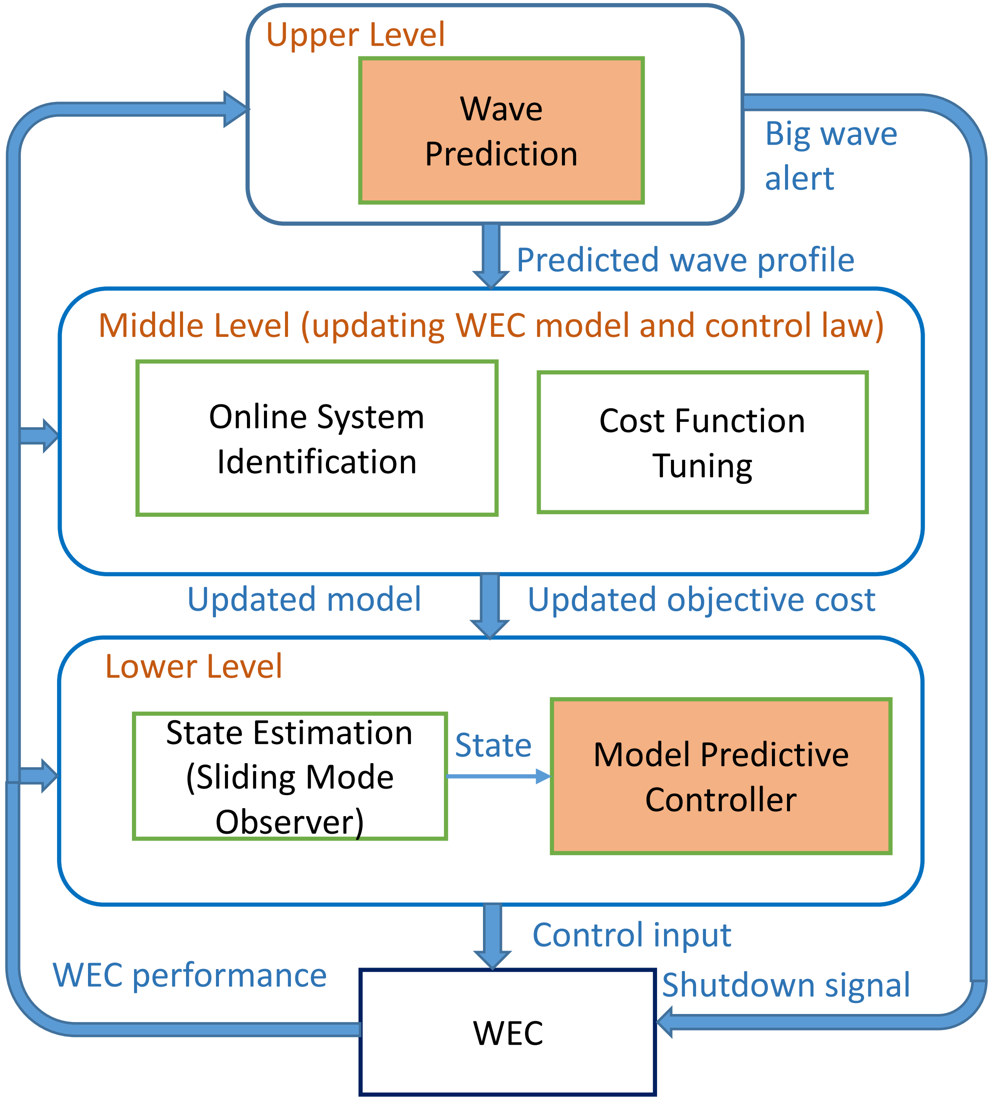
- ***Upper level – wave prediction***
  i. Quiescent Period Wave Prediction technique to send detrimental wave alert to shut down WEC.
  ii. Deterministic Sea Wave Prediction to predict wave profile.
- ***Middle level – update WEC model and control law***
  i. Online WEC model identification using adaptive parameter estimation.
  ii. Adaptive tuning of control law.

Fast convergence of adaptive online parameter identification of dynamic parameters



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

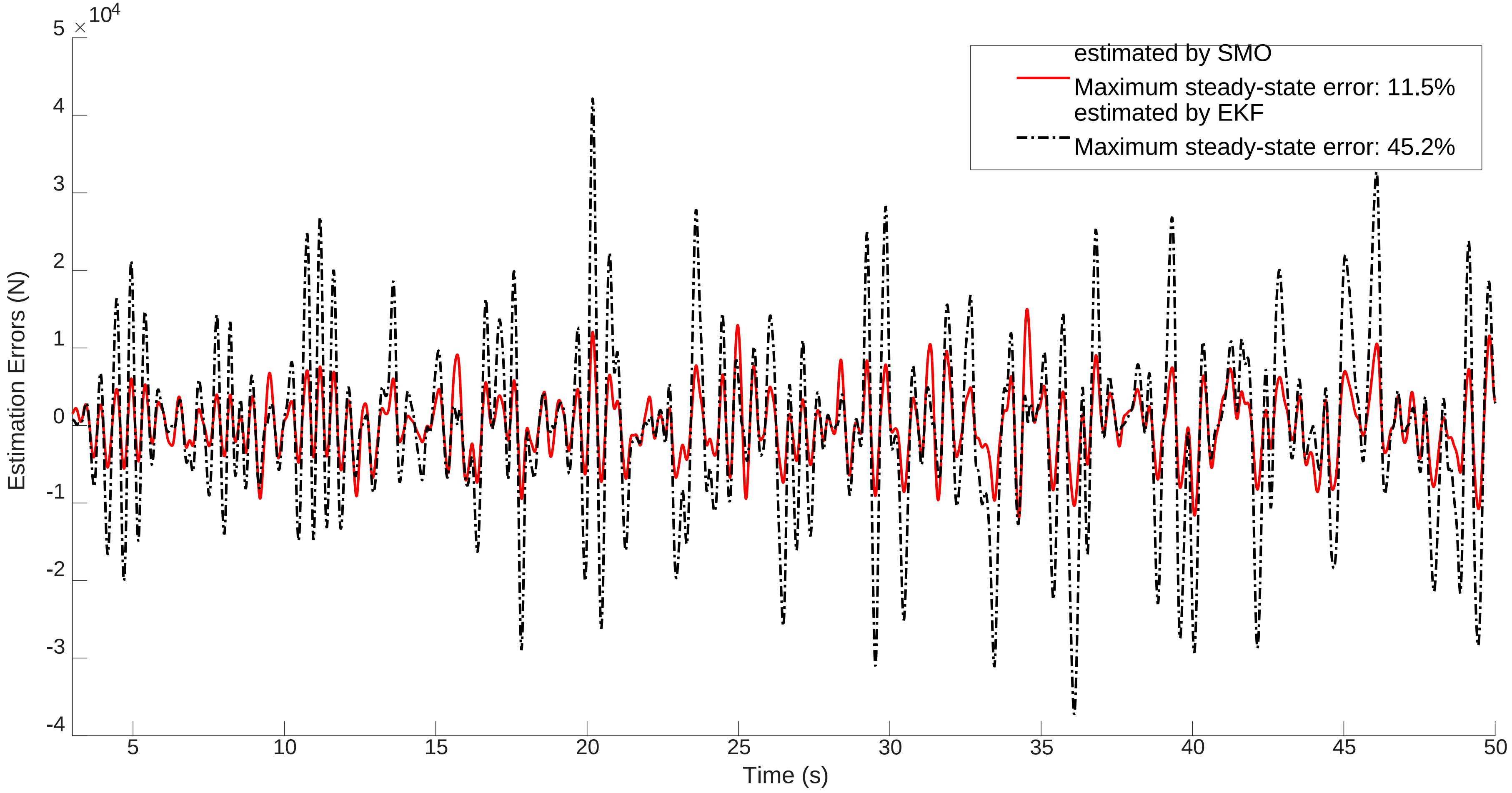
The proposed control framework



How it works:

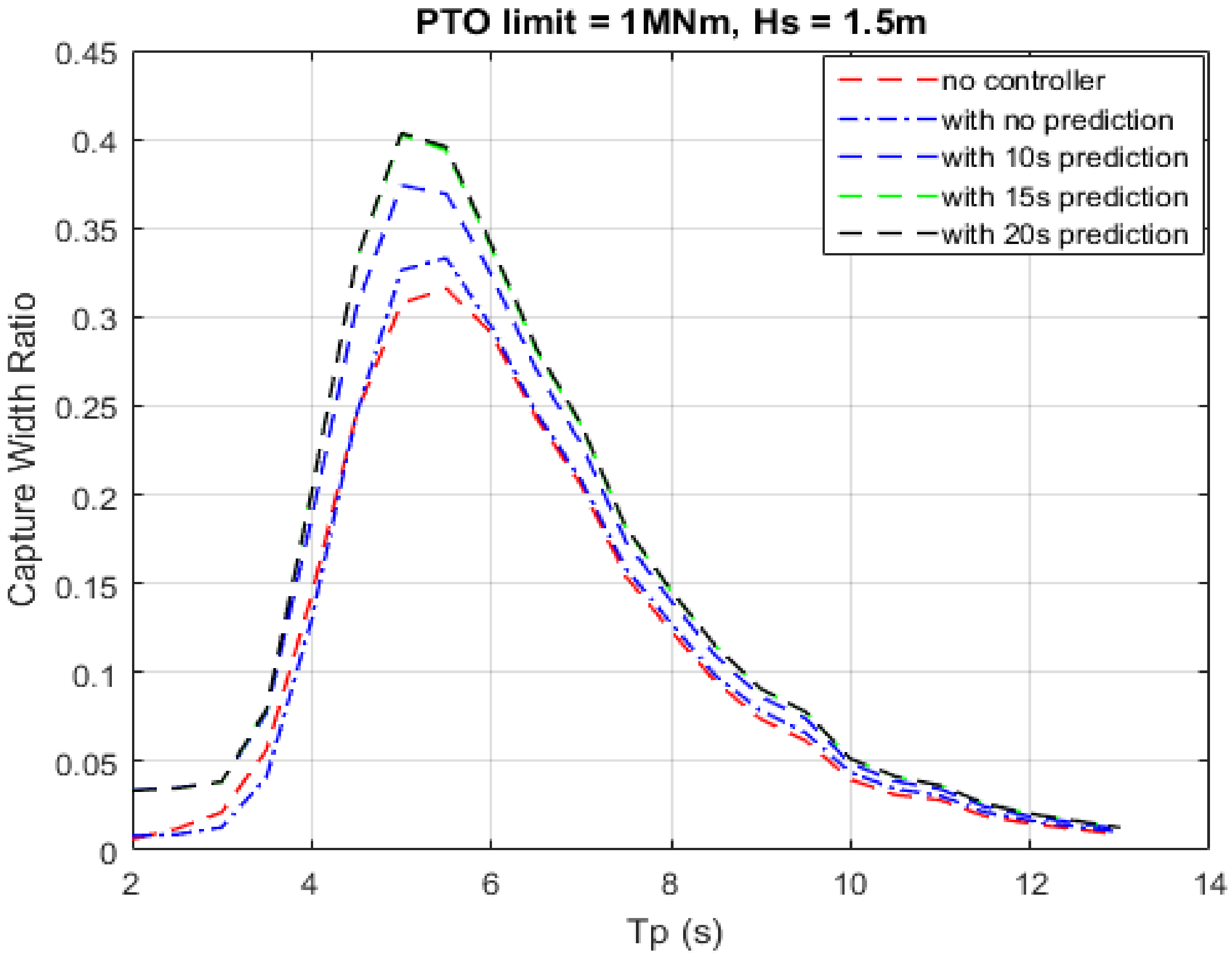
- ***Upper level – wave prediction***
  i. Quiescent Period Wave Prediction technique to send detrimental wave alert to shut down WEC.
  ii. Deterministic Sea Wave Prediction to predict wave profile.
- ***Middle level – update WEC model and control law***
  i. Online WEC model identification using adaptive parameter estimation.
  ii. Adaptive tuning of control law.
- ***Lower level – energy maximisation control***
  i. Accurate estimation of excitation force and states by Siding Mode Observer.
  ii. Non-causal energy maximisation control subject to constraints by Model Predictive Control (MPC).

Sliding Mode Observer provides more accurate excitation force estimation than EKF



Sliding mode observer enables more accurate excitation force estimation than Extended Kalman Observer

Model Predictive Control performance - Capture Width Ratio



The main findings

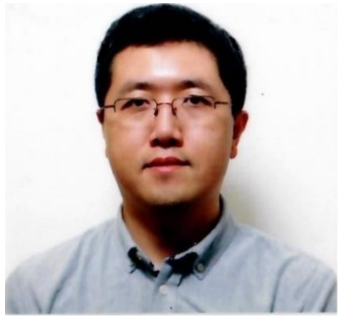
- Energy output can be improved by 30%-90% by proposed control strategies in different scenarios.
- Wave prediction plays a major role in achieving this improvement.
- The proposed control scheme is very robust to a) wave prediction accuracy, b) modelling uncertainties, c) change of sea states.

Selected publications partially supported by this project

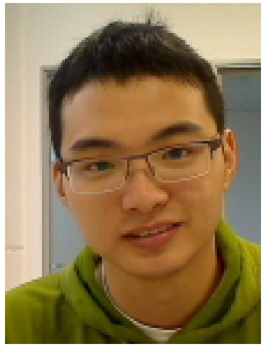
- S. Zhan and G. Li*, Linear optimal noncausal control of wave energy converters, IEEE Transactions on Control Systems Technology, published online.
- J. Na, B. Wang, G. Li*, S. Zhan, and W. He, Nonlinear Constrained Optimal Control of Wave Energy Converters with Adaptive Dynamic Programming, IEEE Transactions on Industrial Electronics, published online.
- J. Na, G. Li*, B. Wang, G. Herrmann, S. Zhan, Robust Optimal Control of Wave Energy Converters Based on Adaptive Dynamic Programming, IEEE Transactions on Sustainable Energy, published online.
- S. Zhan and G. Li, A reliable optimal controller design methodfor seawave energy converters, the 12th European Wave and Tidal Energy Conference, Cork, Ireland, September, 2017.
- S. Zhan, B. Wang, J. Na, G. Li*, Adaptive Optimal Control of Wave Energy Converters, to be presented at the 11th IFAC Conference on Control Applications in Marine Systems, Robotics, and Vehicles, Opatija, Croatia, Sep. 10-12, 2018.
- Z. Liao, G. Nian,P. Stansby and G. Li*, Control-Oriented Modelling for Wave Energy Converter M4, the 4th Asian Wave and Tidal Energy Conference (AWTEC 2018), Taipei, Taiwan, Sep. 9-13, 2018.
- J. Na, G. Li*, S. Zhan, Online Optimal Control of Wave Energy Converters Via Adaptive Dynamic Programming, American Control Conference, Milwaukee, June, 2018.

The Team

QMUL:



Dr Guang Li
(Project Leader)



Dr Siyuan Zhan
(Controller design)

Mr Zhijing Liao
(Modelling)

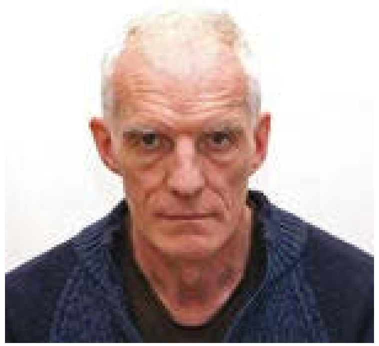
Dr Yao Zhang
(State/force estimation)

Mocean:

Dr Cameron McNatt
(Hydrodynamic modelling)

Dr Chris Retzler
(System configuration)

Exeter:



Prof Mike Belmont
(Wave prediction)

Prof Chris Edwards
(Uncertainties)

IMPACT – Integrated Marine Point Absorber Control Tool

Wave Energy Scotland Annual Conference 2018

woodplc.com

IMPACT – Integrated Marine Point Absorber Control Tool

Project Overview

- Milestone 1
  - Development of 4 "exemplar WEC" models
  - Design basis for controller design
  - Controllers for WEC types 1 and 2
- Milestone 2
  - Controllers for WEC types 3 and 4
- Milestone 3
  - Open source control tool for model development and controller design
  - User manual for the control tool
- Milestone 4
  - Physical testing FEED report
  - Controller hardware FEED report
  - Implementation on a software model of a real WEC
  - Final reporting

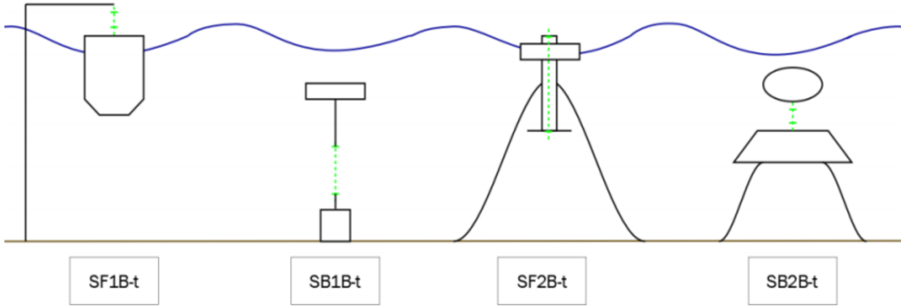
Project Team

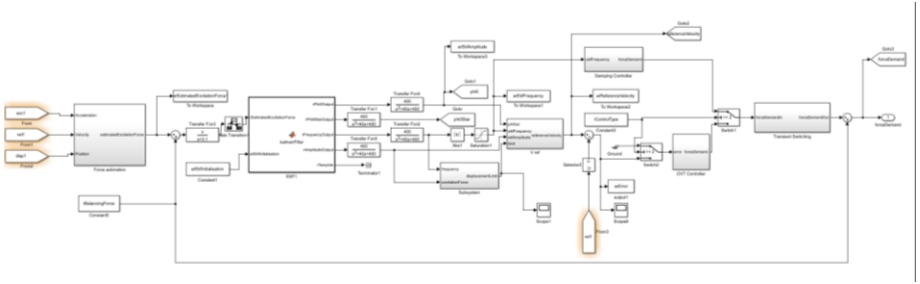
Thanks for valuable additional input from the industry advisory board and also particularly from Carnegie and Trident, who have provided much of the required information for the activities in Milestone 4.

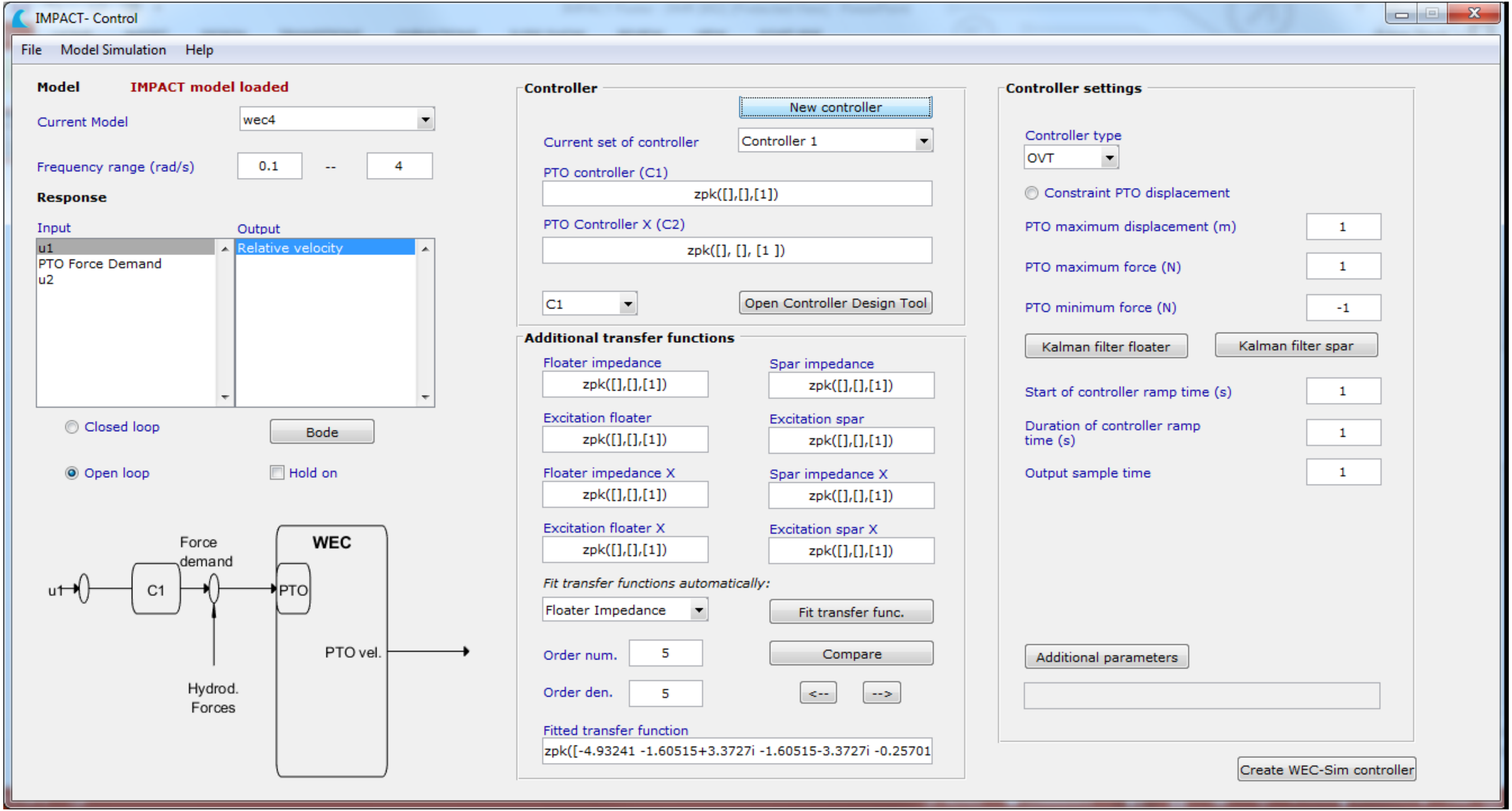
IMPACT – Integrated Marine Point Absorber Control Tool

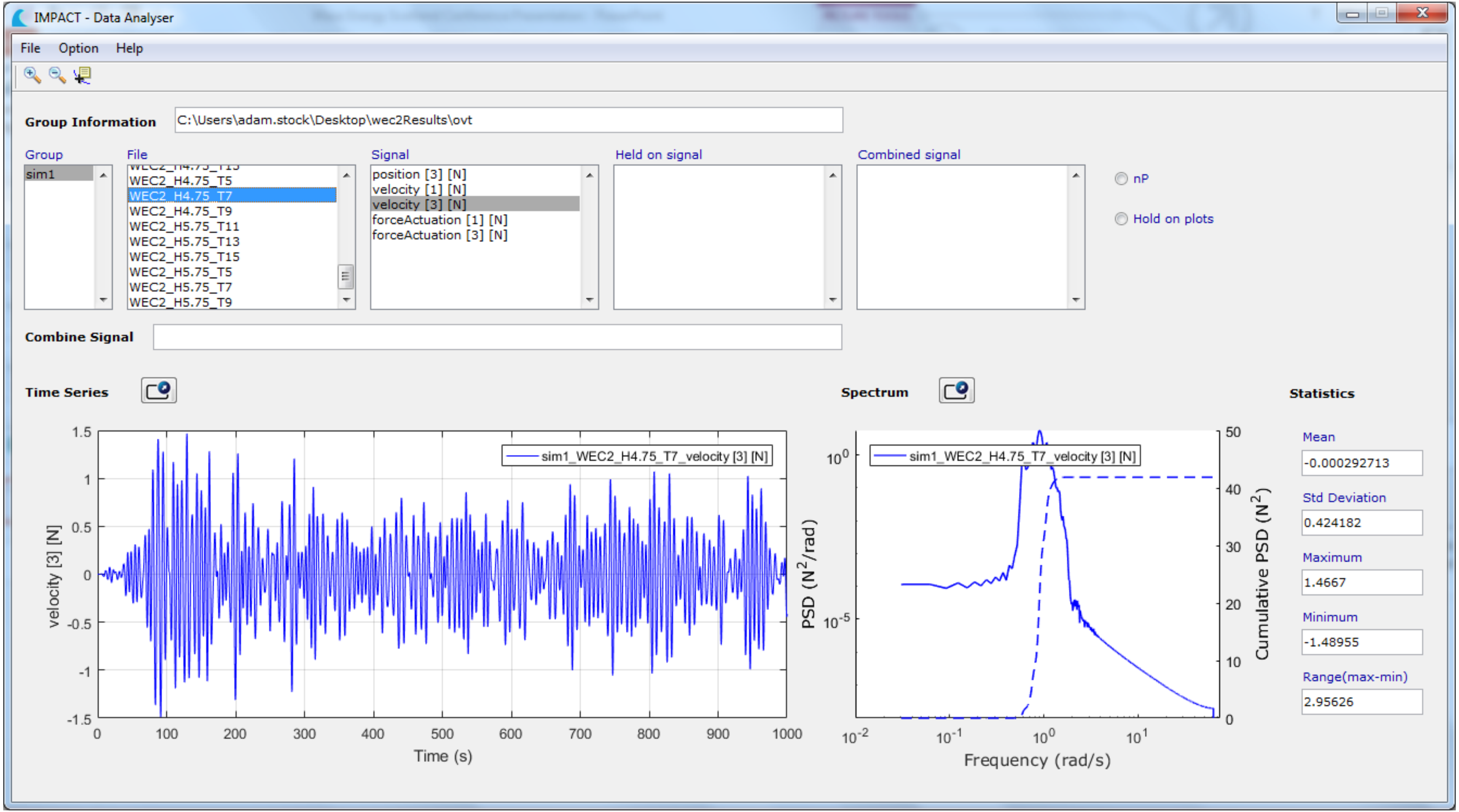
IMPACT toolbox

- IMPACT allows the design of Optimal Velocity Tracking (OVT) controllers for the four types of WEC shown
- As well as OVT, adaptive linear damping (linear damping with a variable gain based on the excitation force) can also be implemented.
- Models generated by IMPACT could also be used to help develop MPC techniques
- IMPACT has an easy to use General User Interface (shown on the next slide) to allow control models and controllers to be quickly designed and assessed.
- IMPACT also includes a data analyser to make interrogation of WEC-Sim simulations much easier



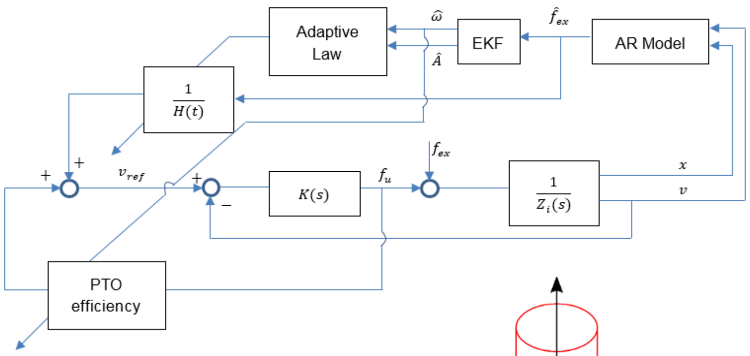


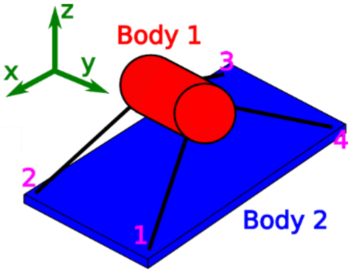

IMPACT- Control
File
Model Simulation
Help
Model
IMPACT model loaded
Current Model
wec4
Frequency range (rad/s)
0.1
--
4
Response
Input
Output
u1
PTO Force Demand
u2
Relative velocity
Closed loop
Bode
Open loop
Hold on
Force
demand
WEC
u1
C1
PTO
PTO vel.
Hydrod.
Forces
Controller
New controller
Current set of controller
Controller 1
PTO controller (C1)
zpk([],[],[1])
PTO Controller X (C2)
zpk([], [], [1])
C1
Open Controller Design Tool
Additional transfer functions
Floater impedance
zpk([],[],[1])
Spar impedance
zpk([],[],[1])
Excitation floater
zpk([],[],[1])
Excitation spar
zpk([],[],[1])
Floater impedance X
zpk([],[],[1])
Spar impedance X
zpk([],[],[1])
Excitation floater X
zpk([],[],[1])
Excitation spar X
zpk([],[],[1])
Fit transfer functions automatically:
Floater Impedance
Fit transfer func.
Order num.
5
Compare
Order den.
5
<--
-->
Fitted transfer function
zpk([-4.93241 -1.60515+3.3727i -1.60515-3.3727i -0.25701
Controller settings
Controller type
OVT
Constraint PTO displacement
PTO maximum displacement (m)
1
PTO maximum force (N)
1
PTO minimum force (N)
-1
Kalman filter floater
Kalman filter spar
Start of controller ramp time (s)
1
Duration of controller ramp time (s)
1
Output sample time
1
Additional parameters
Create WEC-Sim controller

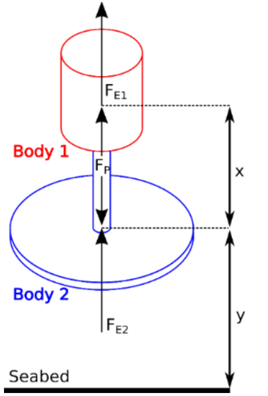

IMPACT - Data Analyser
File
Option
Help
Group Information
C:\Users\adam.stock\Desktop\wec2Results\ovt
Group
sim1
File
WEC2_H4.75_T5
WEC2_H4.75_T7
WEC2_H4.75_T9
WEC2_H5.75_T11
WEC2_H5.75_T13
WEC2_H5.75_T15
WEC2_H5.75_T5
WEC2_H5.75_T7
WEC2_H5.75_T9
Signal
position [3] [N]
velocity [1] [N]
velocity [3] [N]
forceActuation [1] [N]
forceActuation [3] [N]
Held on signal
Combined signal
nP
Hold on plots
Combine Signal
Time Series
Spectrum
Statistics
sim1_WEC2_H4.75_T7_velocity [3] [N]
velocity [3] [N]
Time (s)
PSD (N^2/rad)
Cumulative PSD (N^2)
Frequency (rad/s)
Mean
-0.000292713
Std Deviation
0.424182
Maximum
1.4667
Minimum
-1.48955
Range(max-min)
2.95626

IMPACT – Integrated Marine Point Absorber Control Tool

Optimal Velocity Tracking





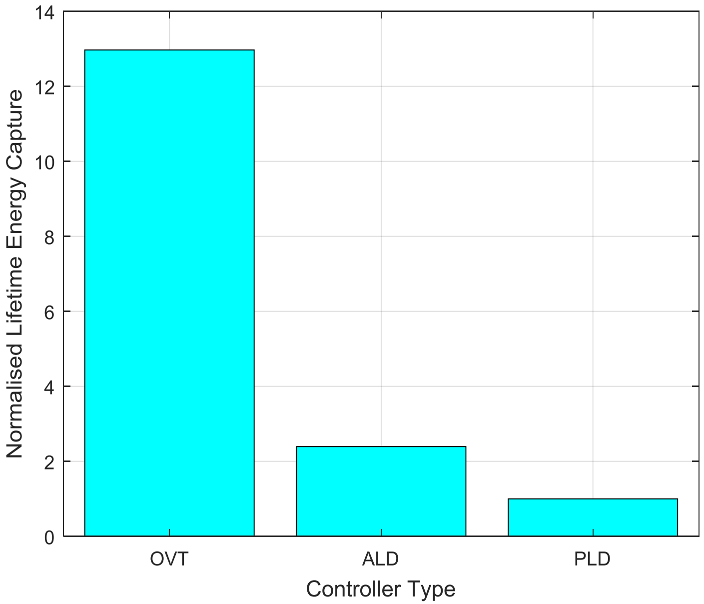


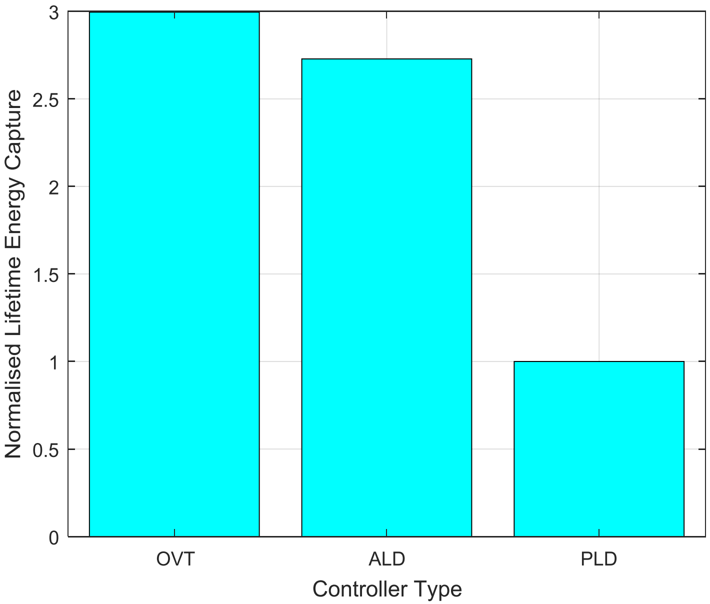
- The controller used is based on the Optimal Velocity Tracking (OVT) controller methodology proposed by Fusco and Ringwood
- Estimates of the excitation force, including its amplitude and frequency inform an optimal speed
- The optimal speed is tracked by a set-point tracking controller
- No expensive equipment required:
  - Lean algorithm
  - Minimal sensing requirements
- Applied to two body WECs for the first time

IMPACT – Integrated Marine Point Absorber Control Tool

Controller Performance

- Examples are given below of the increase in energy output for OVT and ALD compared to passive linear damping for WEC types 1 (left) and 3 (right) over a typical range of Scottish waters sea conditions. It is clear that the WEC design has a large effect on the amount of extra energy OVT can capture





Thank-you

WES Annual Conference 2018

Project Progress Updates: Structural Materials and Manufacturing Processes, Stage 2

File Contents

- Arup – Concrete as a Technology Enabler [8 pages]
- CorPower – HydroComp [8 pages]
- Tension Technology International – NetBuoy [5 pages]

WES CREATE

Concrete as a Technology Enabler

WES Annual Conference | December 2018

ARUP

cruz atcheson
CONSULTING ENGINEERS

mpa
The Concrete Centre

DOOSAN

mocean energy

Carnegie
wave energy

George Walker | Arup
george-a.walker@arup.com
+44 20 7755 2502

Design Choice: Reinforced Concrete vs. Steel

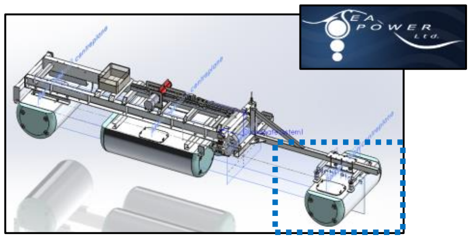
Reinforced concrete has the potential to offer **a robust and low cost solution** taking advantage of a **mature supply chain**: the focus of the CREATE project.

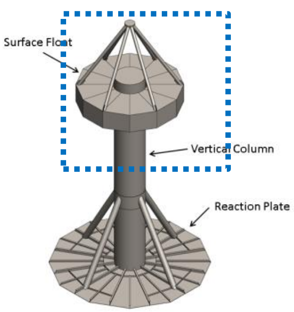
	Reinforced Concrete	**Steel**
Material Properties	Strength ~ 50 MPa Density ~ 2600 kgm^{-3}	Strength ~ 350 MPa Density ~ 8000 kgm^{-3}
	Concrete solutions are likely to be heavier than steel	
Lower Unit Cost	Lower unit and fabrication cost	Higher unit and fabrication cost
High TRL and Mature Supply Chain	Mature supply chain with simpler fabrication available at more locations	More specialist and less available fabrication methods
High Durability	• Corrosion resistant • Less maintenance overhead • Better fatigue performance (typically)	• Corrosion protection required • Worse fatigue performance (typically)

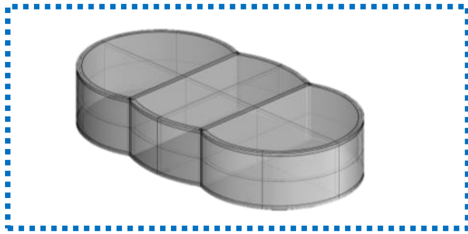
ARUP

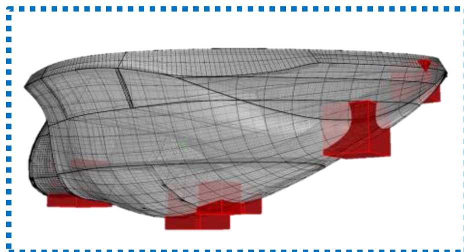
CREATE Stage 1: Engineering Design Study

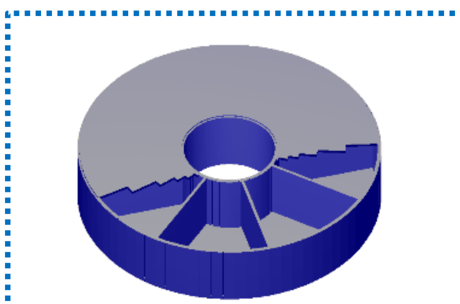
Stage 1 of the CREATE project (2017) took a **sector wide approach** to identify where concrete had potential for WEC structures and developed the **most promising option to a pre-FEED level** with potential for commercialisation.

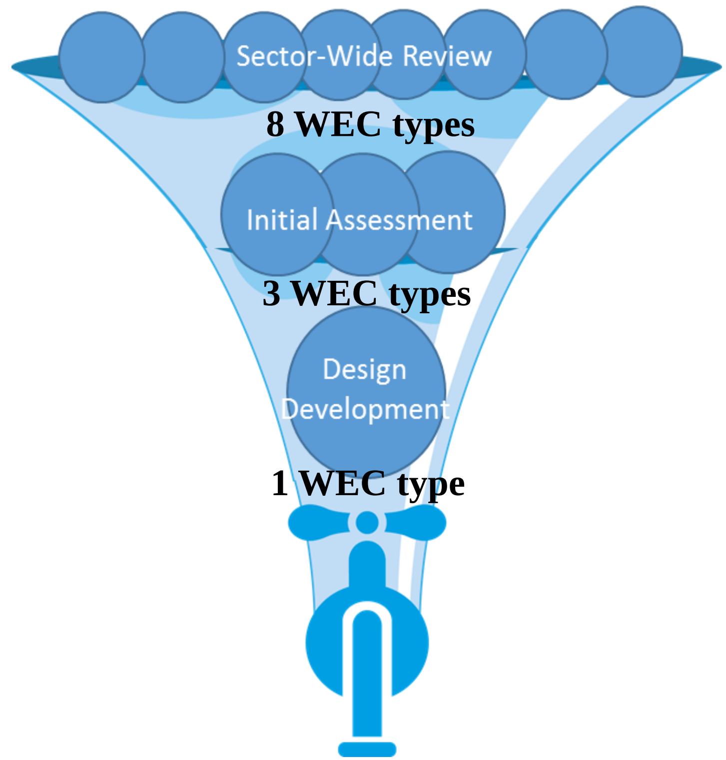




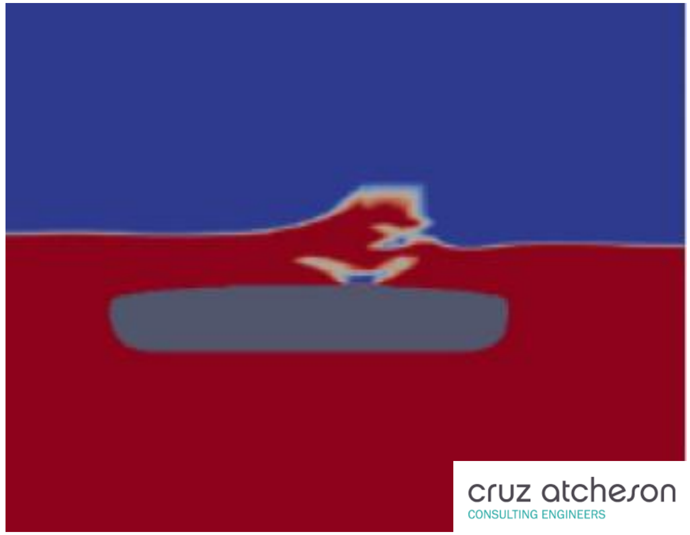


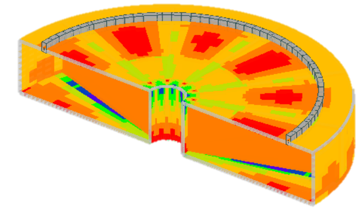


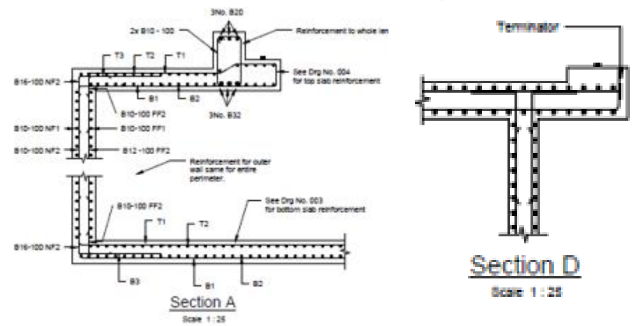


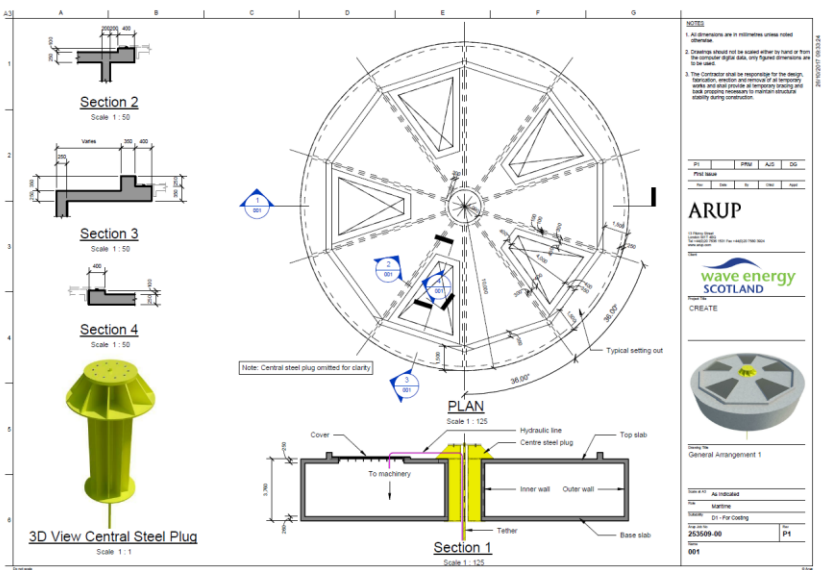


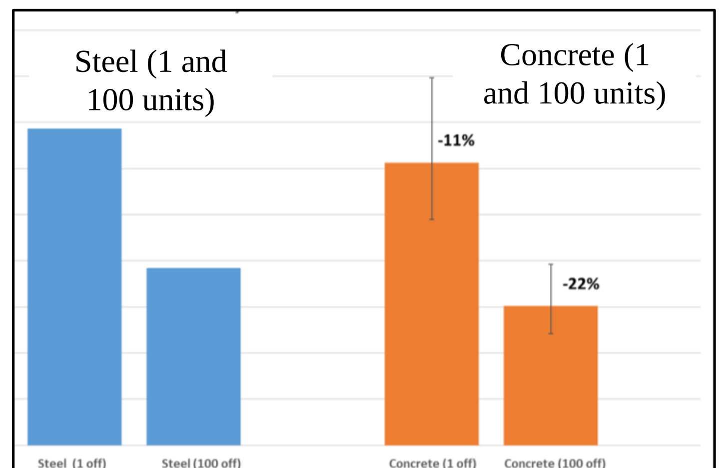
CREATE Stage 1: Engineering Design Study









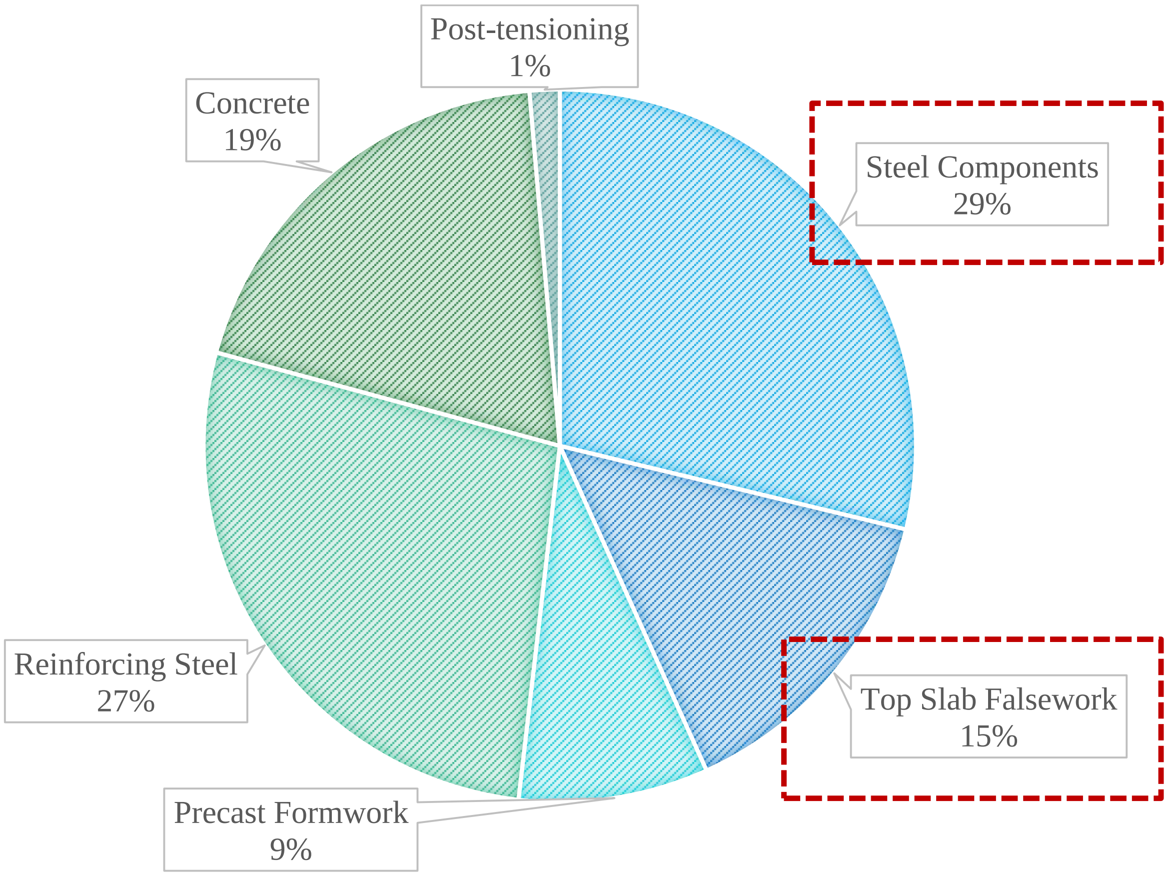


BA CAPEX Comparison

ARUP

CREATE Stage 2: Cost and Risk Reduction

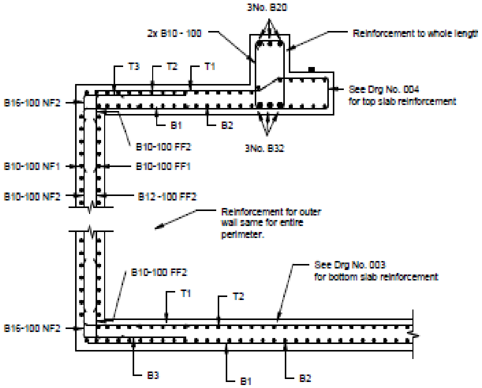
Stage 2 of the CREATE project aims to **mitigate key technical risks** identified in Stage 1 and provide confidence that **concrete can provide a step change in LCoE** for WECs.



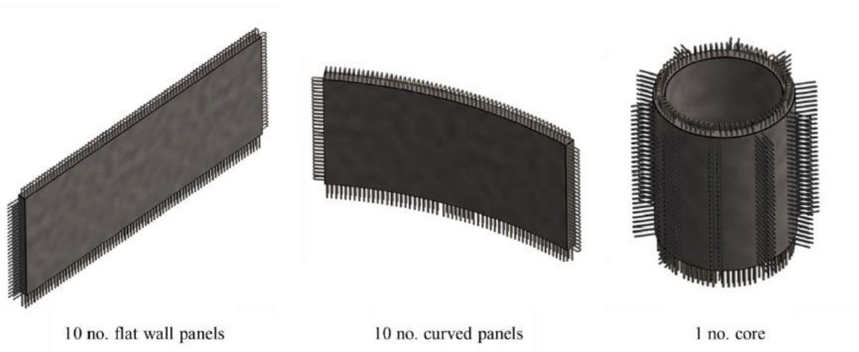
<u>Carnegie Concrete CETO 6 BA: Cost Breakdown</u>

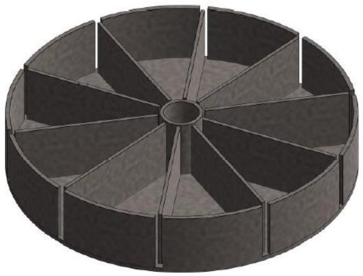
ARUP

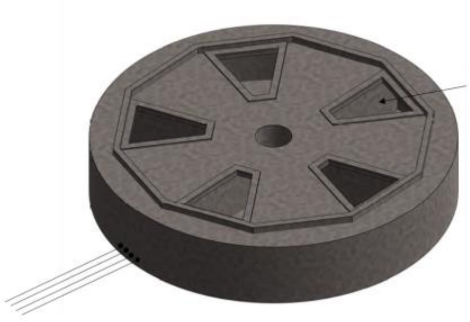
CREATE Stage 2: Cost and Risk Reduction



<u>Optimisation of Key Cost Centres</u>





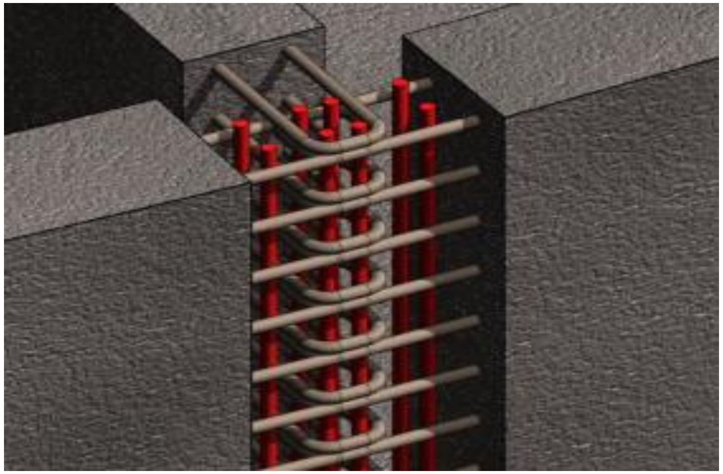


<u>Design for Manufacture: Precast Concrete BA</u>

mpa
The Concrete Centre

ARUP

CREATE Stage 2: Cost and Risk Reduction



DOOSAN

Precast Concrete Connection: Watertightness Testing

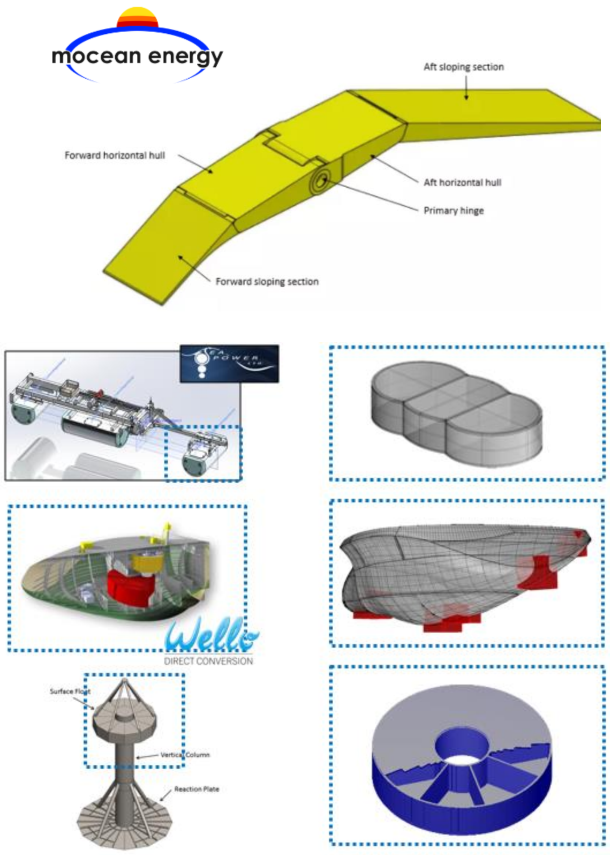
mpa The Concrete Centre

bam nuttall

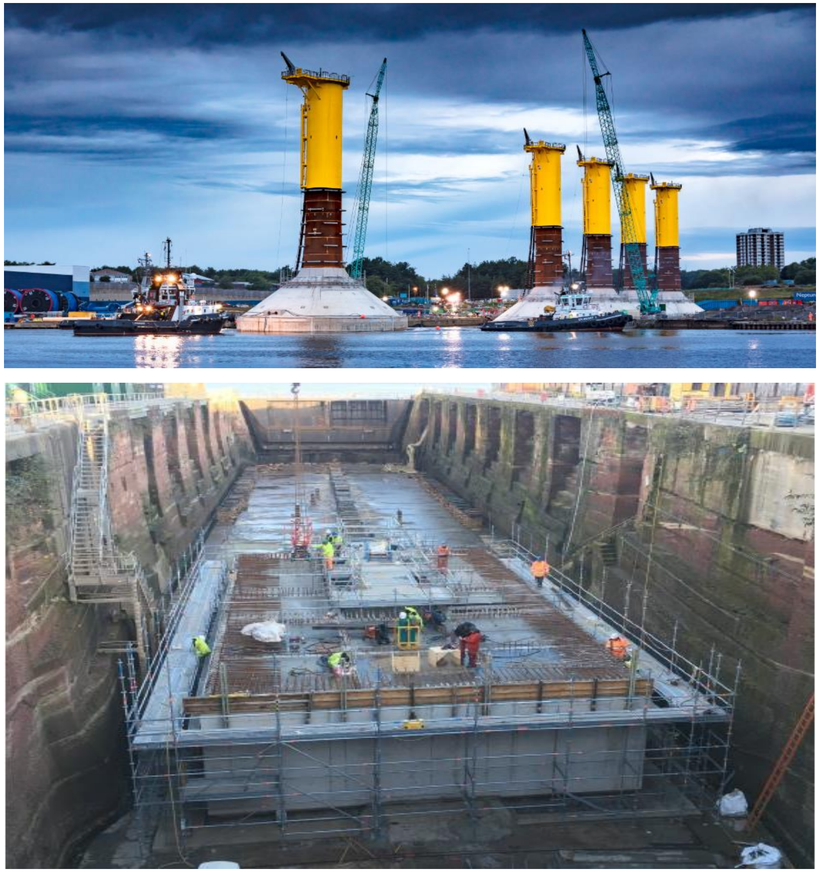
Independent Cost and Manufacturing Assessment

CREATE Stage 2: Conclusions

Stage 2 of the CREATE project aims to **mitigate key technical risks** identified in Stage 1 and provide confidence that **concrete can provide a step change in LCoE** for WECs.



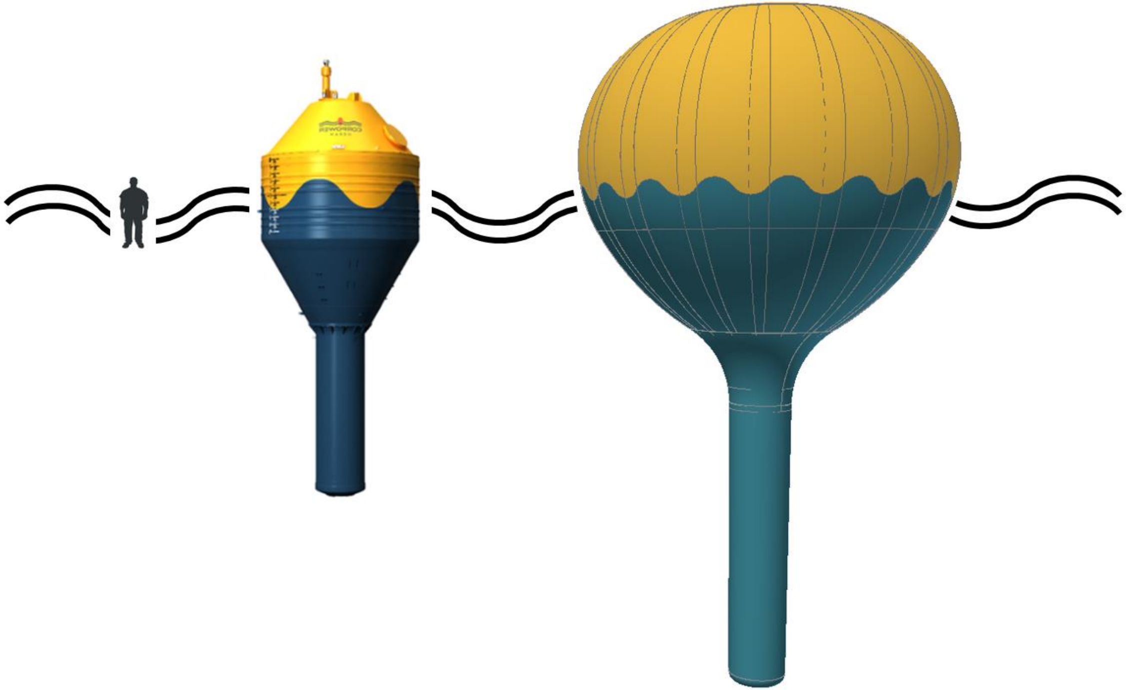
<u>Demonstration of the Versatility of Concrete for WECs</u>



<u>Low Cost, High TRL Solution Ready for Detailed Design</u>

ARUP

HydroComp Stage 2 - SMMP



HydroComp Stage 2 - SMMP

Project Summary

Stage 2 Aim - Successful demonstration of the HydroComp Stage 1 solution through material testing and techno-economic performance assessment

Stage 1 Hull

- Hull Design
  - Panel-only
- Material
  - GRP composite

Design Refinement →

Practical Testing →

Stage 2 Hull

- Hull Design
  - Thinner panels + internal frame
- Material
  - HE-Glass

HydroComp Stage 2 - SMMP

Challenges

Performance
- Minimise panel deflection
- Reduce drag
- Increase buoyancy
- Computational Assessment

Affordability
- Material cost
- Ease of assembly
- Supply-chain logistics
- Transportation

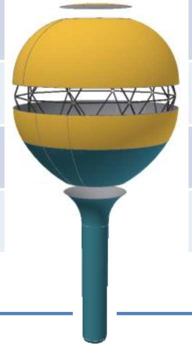
Hull

Availability
- Maintenance access
- Repair of damaged hull sections
- Hull maintenance

Survivability
- Material performance
- Bond performance
- Exposure to marine environment
- 20 year life expectancy

HydroComp Stage 2 - SMMP

	Configuration options				
	Panels			Wound	
	Panels-only	Panels + sub-frame		Parts	One-piece
	Reinforced	Constant thickness			
	(achieved via thin panels + thicker panels)	Minimal sub-frame	Substantial sub-frame	inc. sub-frame	inc. sub-frame
Performance					
Manufacture					
Assembly					
Logistics					

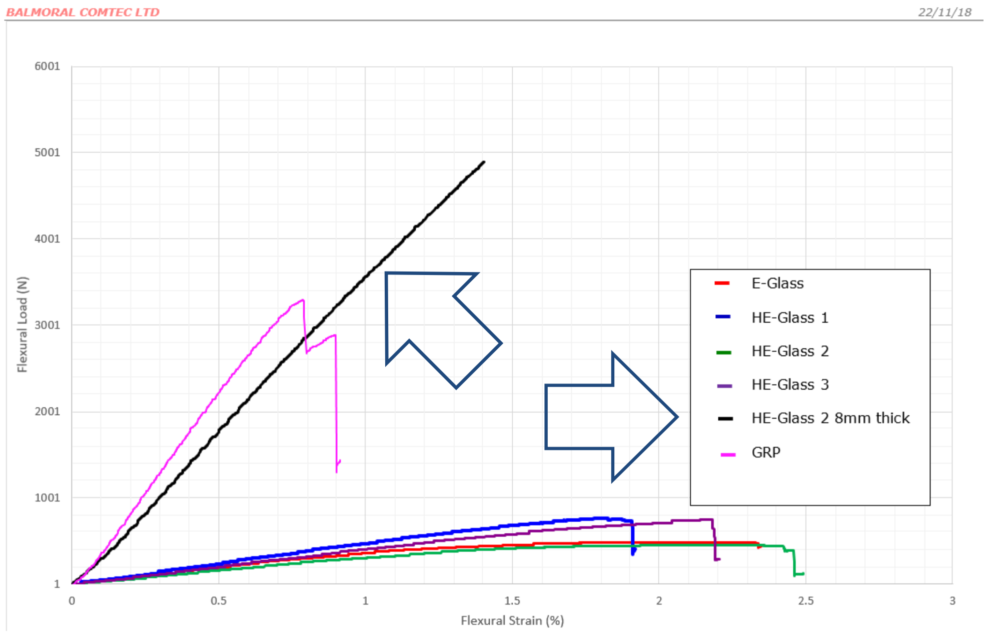


HydroComp Stage 2 - SMMP

Material Change

HE-Glass 2

- HE-Glass 2 optimises ply weight and resin percentage for HydroComp Project
- 8mm. thick HE-Glass 2
 (compared against 10mm. thick GRP material from Stage 1)
- Manufacturing costs of panels for GRP are significantly higher than HE-Glass

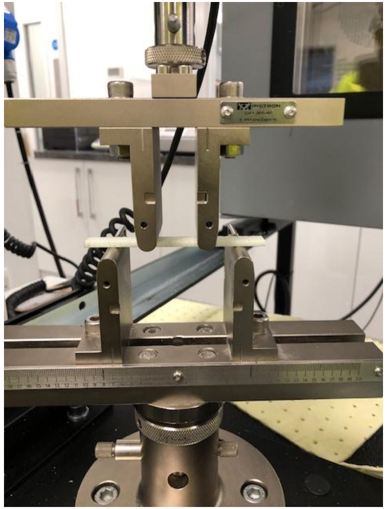


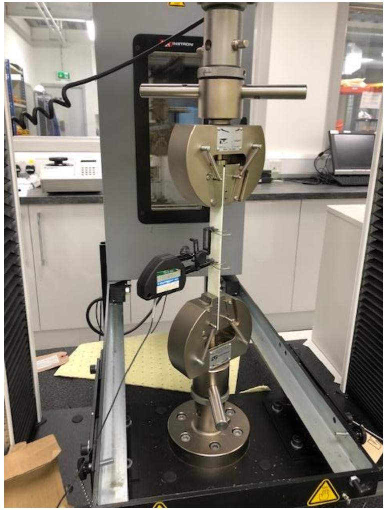
HydroComp Stage 2 - SMMP

Technical Testing

HE-Glass

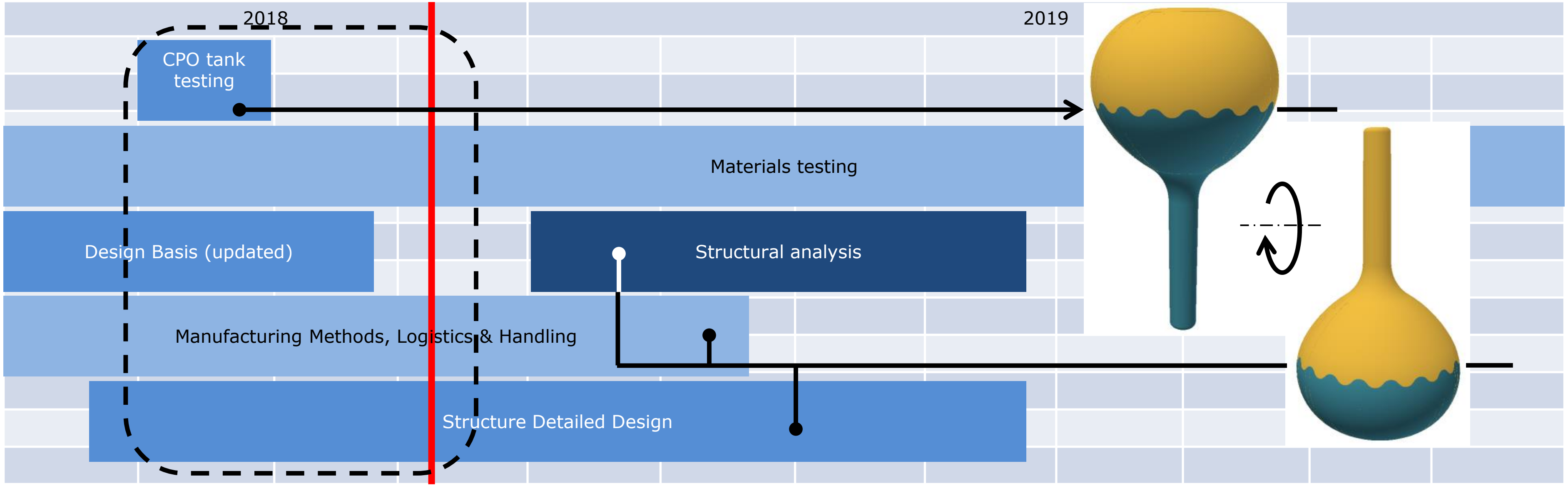
- Material Performance
  - 4-point bend
  - Tensile
- Bond Performance
  - 4-point bend
  - Tensile
- Exposure to marine environment
  - Weathering testing



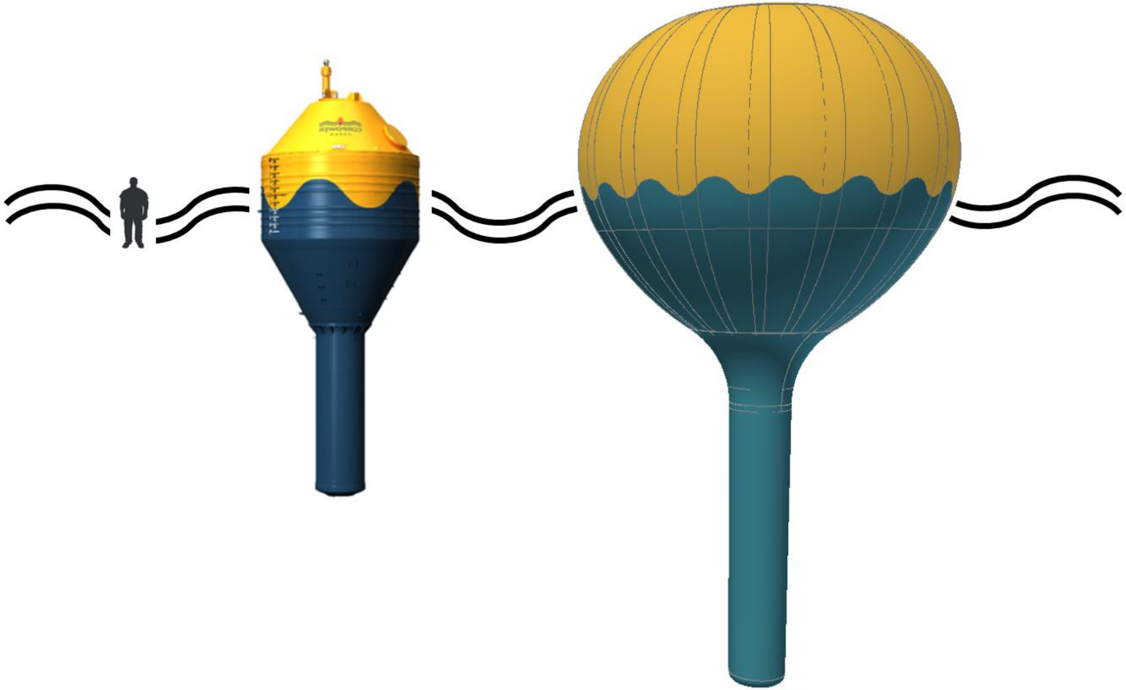


HydroComp Stage 2 - SMMP

Project timeline



HydroComp Stage 2 - SMMP



TTI NETBUOY STAGE 2 PROJECT

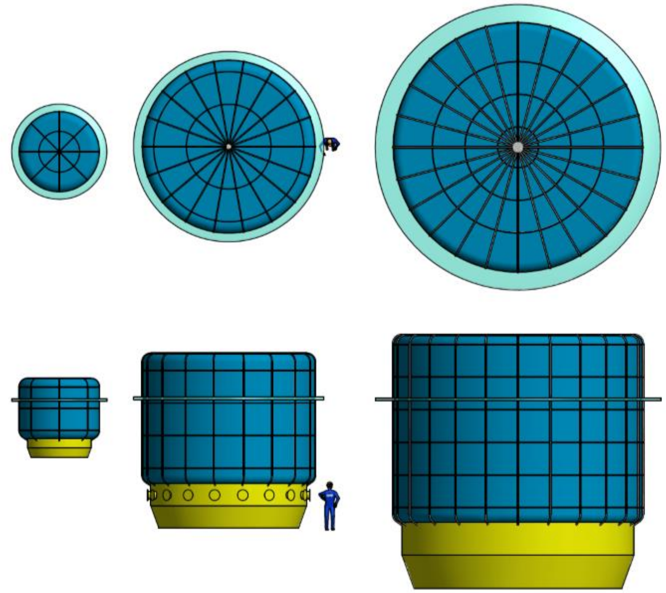
Lead Contractor:
Tension Technology International Ltd, Inverness

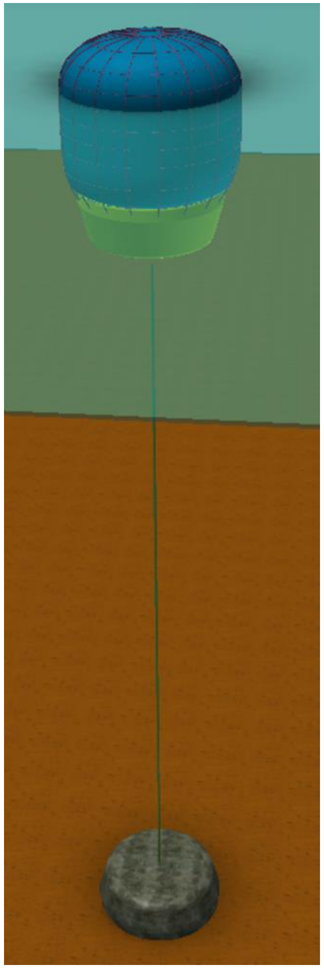
Quoceant Innovation Offshore

OPTIMUS

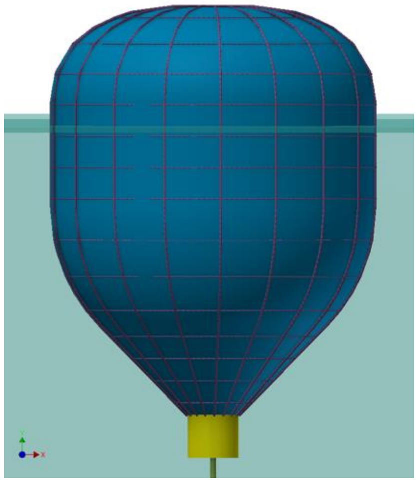
BLACK & VEATCH

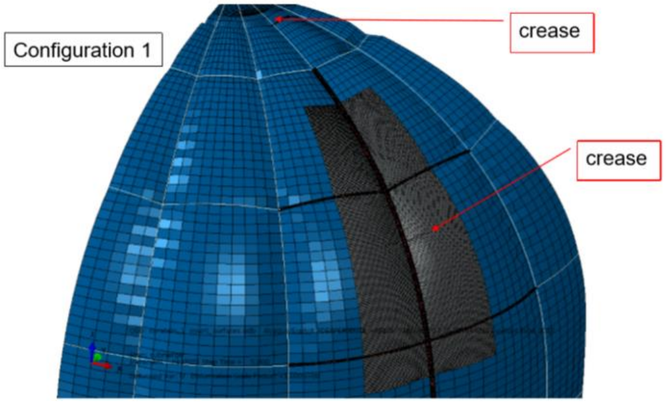
University of Strathclyde





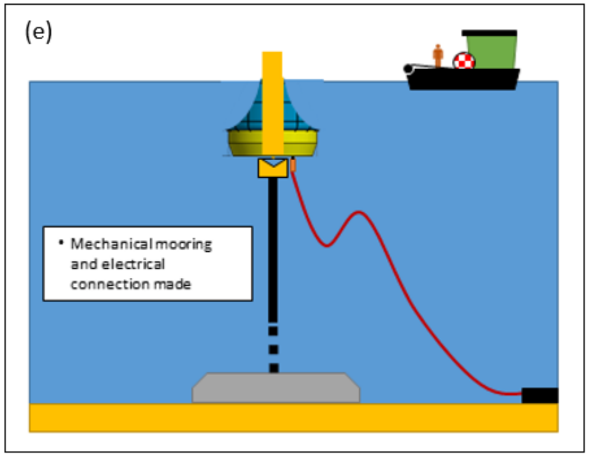
TTI NETBUOY STAGE 1 update

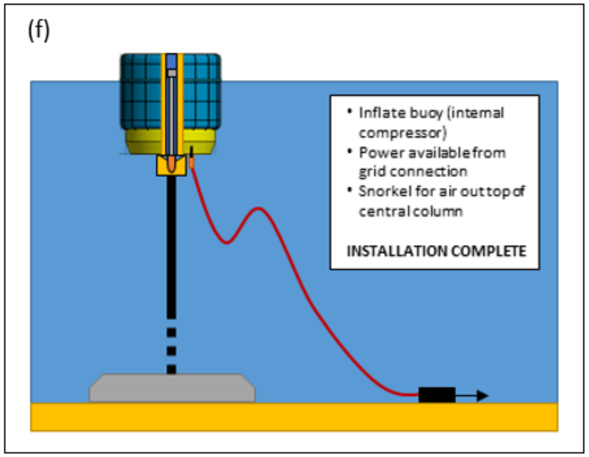




Completed concept design engineering. Including

- Material Selection
- Non-linear FEA
- Orcaflex net-modelling
- Manufacturing assessment

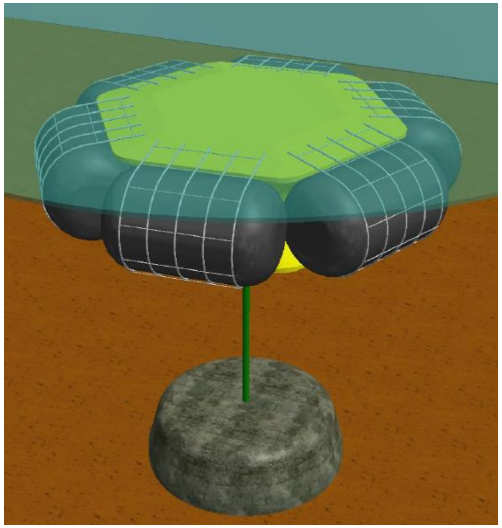


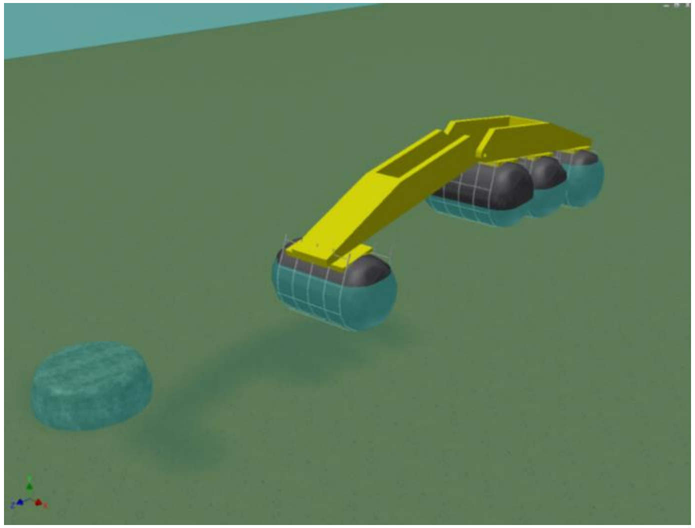


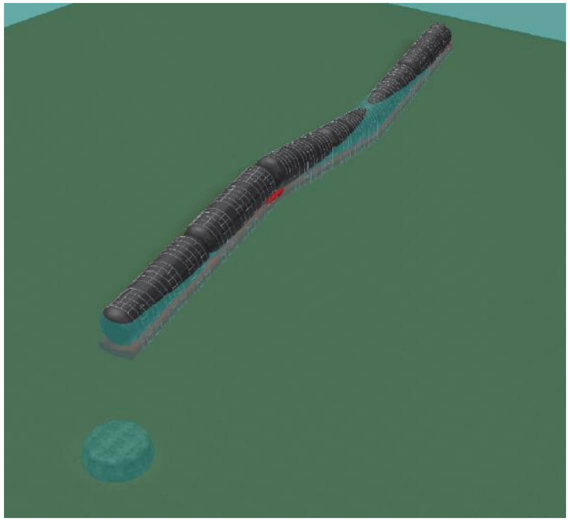
Benchmarking Netbuoy with Steel based point absorber

- Impact on LCOE
- Marine transportation & installation studies

TTI NETBUOY STAGE 1 update



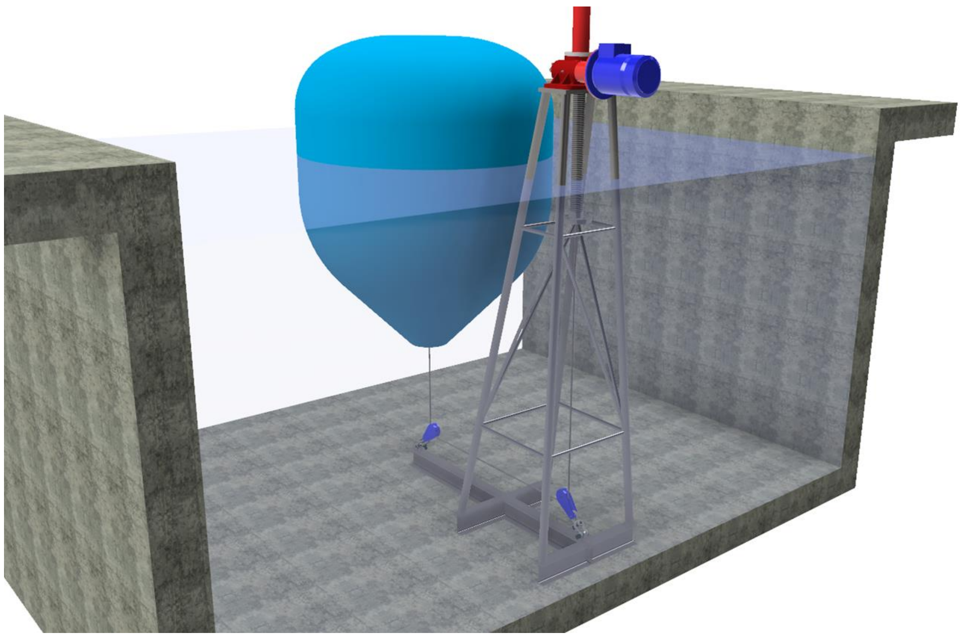




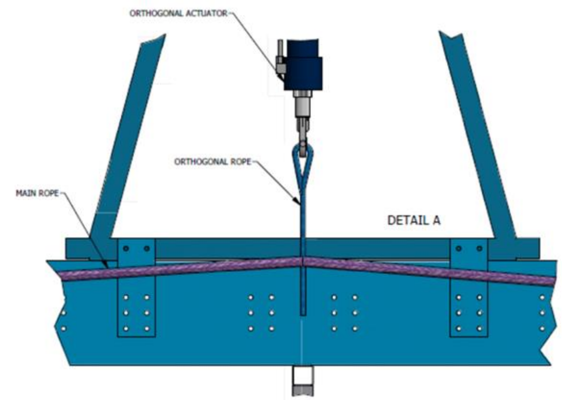
Applicability of Netbuoy technology to other WEC categories

TTI NETBUOY STAGE 2 -Tests

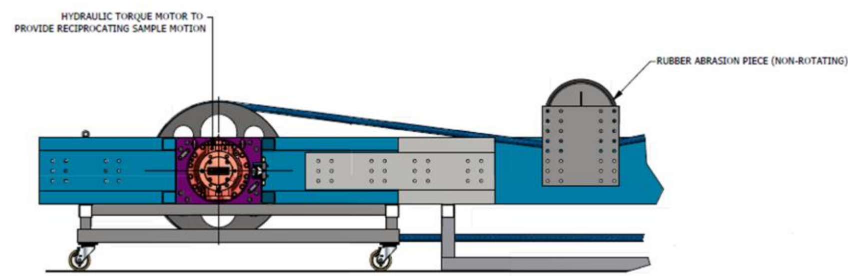
Examples of proposed technology qualification tests (Ref: DNVGL-RP-A203)



Scale full-system tank tests (Hydrostatic & Dynamic)



Full-scale subsystem tests on net joints



Full-scale component net on buoy abrasion

TTI NETBUOY STAGE 2 -Tests

Thank you

For more information contact

Ben Yeats
yeats@tensiontech.com

Tom Mackay
mackay@tensiontech.com

WES Annual Conference 2018

Project Progress Updates: Novel Wave Energy Converter, Stage 2

File Contents

- 4cEngineering – ACER 2 [8 pages]
- AWS – Improved Archimedes Waveswing [10 pages]
- Checkmate – Anaconda [5 pages]
- Mocean – Mocean WEC [6 pages]

4c Engineering

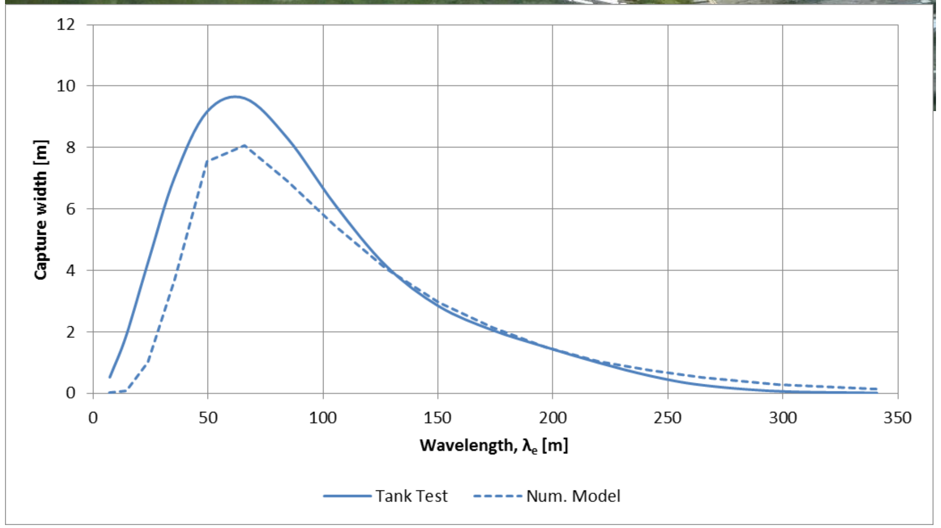
ACER 2 Overview

Andy Hall, Director
4c Engineering

ACER 2 Project Overview

- Where did this project begin?
- What did we do?
- Where are we going?

ACER 2 Project Overview



- Findings from ACER 1
  - Geometry needed to change
  - Structural CAPEX (pontoons/chassis) too high
  - Opportunity for greater optimisation at target sites
- Aims for ACER 2
  - Optimise geometry & reduce CAPEX
  - Continue excellent international collaboration
  - Develop in-house numerical modelling

ACER 2 Project Overview

WP02 Geometry Optimisation

WP07 Model Build
WP08 Tank Testing
WP09 Post-Processing Tank Data

WP09 Numerical Modelling Development & Validation
WP11 Analytical & Numerical Modelling

WP06 LCOE Modelling

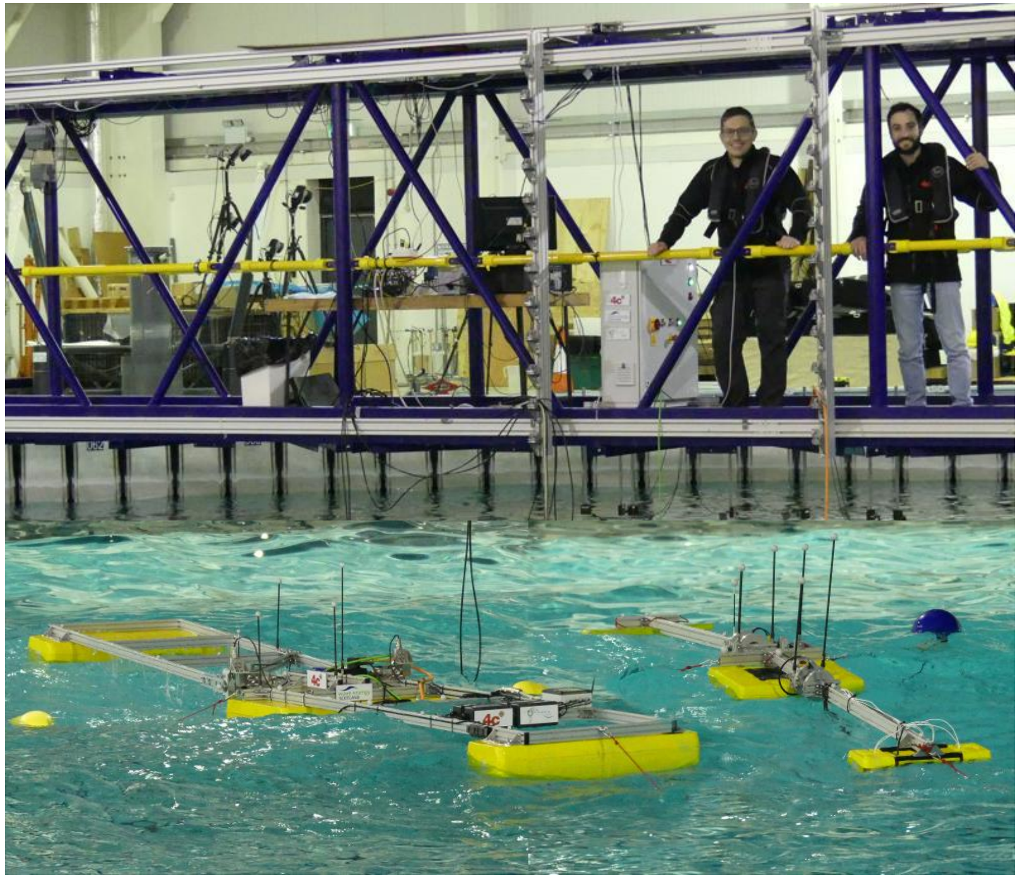
WP03 Full Scale Concept Engineering

WP04 Front End Engineering Design Partial Scale

WP05 Operations Planning
WP12 Subsystem Test Planning

WP13 Stage 3 Test Planning

ACER 2 Project Overview



- 2 x Successful tank test campaigns at FloWave
  - 1:25 Performance
  - 1:50 Loading Characterisation
- Measurements of:
  - Power capture
  - WEC motion
  - Hull pressure
  - Impulse pressures
  - Chassis moments
  - Mooring loads
  - Hinge loads
  - PTO torque

ACER 2 Project Overview

- Cost Targets
  - CAPEX of pontoon reduced from 48% of total WEC CAPEX to 23%
  - Path to LCOE <150 £/MWh still on track
- Performance Targets

$$\frac{Capture\ Width}{Displaced\ Mass} \rightarrow \text{~40\% improvement from ACER 1}$$

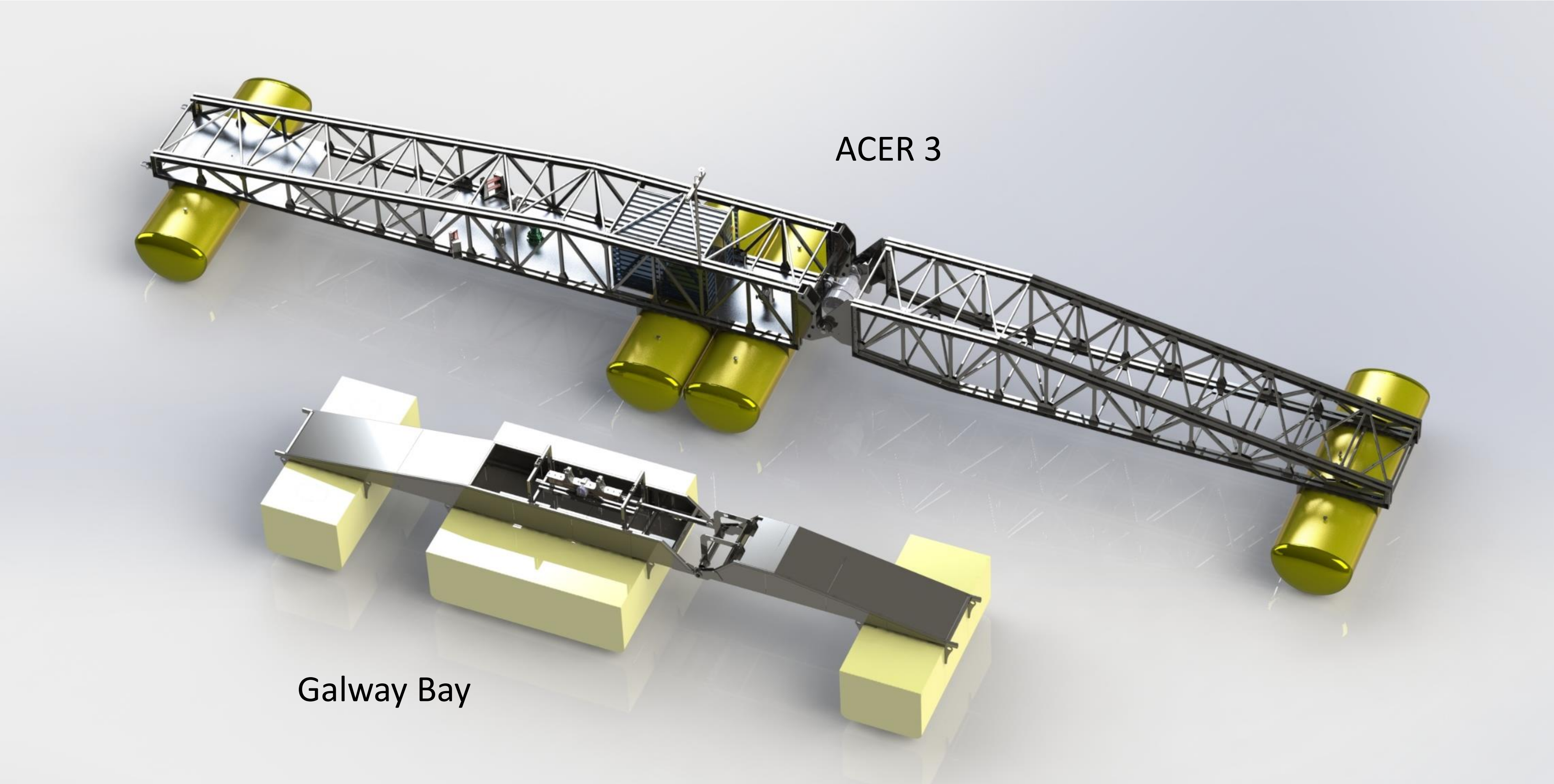
$$\frac{Mean\ Annual\ Energy\ Production}{Displaced\ Mass} \rightarrow \text{>220\% improvement from ACER 1}$$

- Future Planning
  - Storyboarding of construction, assembly & deployment activities
  - Suite of operational plans produced for open water WEC
  - Testing plans developed for WEC & subsystems to progress to TRL 6
  - Supply chain visits

ACER 3 Project Overview

- ACER 3
  - Build on experience from ACER 2 & Sea Power's SmartBay (Galway) demonstrator
  - Planning & design of safe, successful open water WEC testing
  - 2 stage test campaign at EMEC throughout 2020
    - Scapa Flow shake down tests & build operational experience
    - Billia Croo deployment for real sea learning
  - Full scale concept development & commercial activities

WEC development
Galway Bay → ACER 3



AWS Ocean Energy Ltd

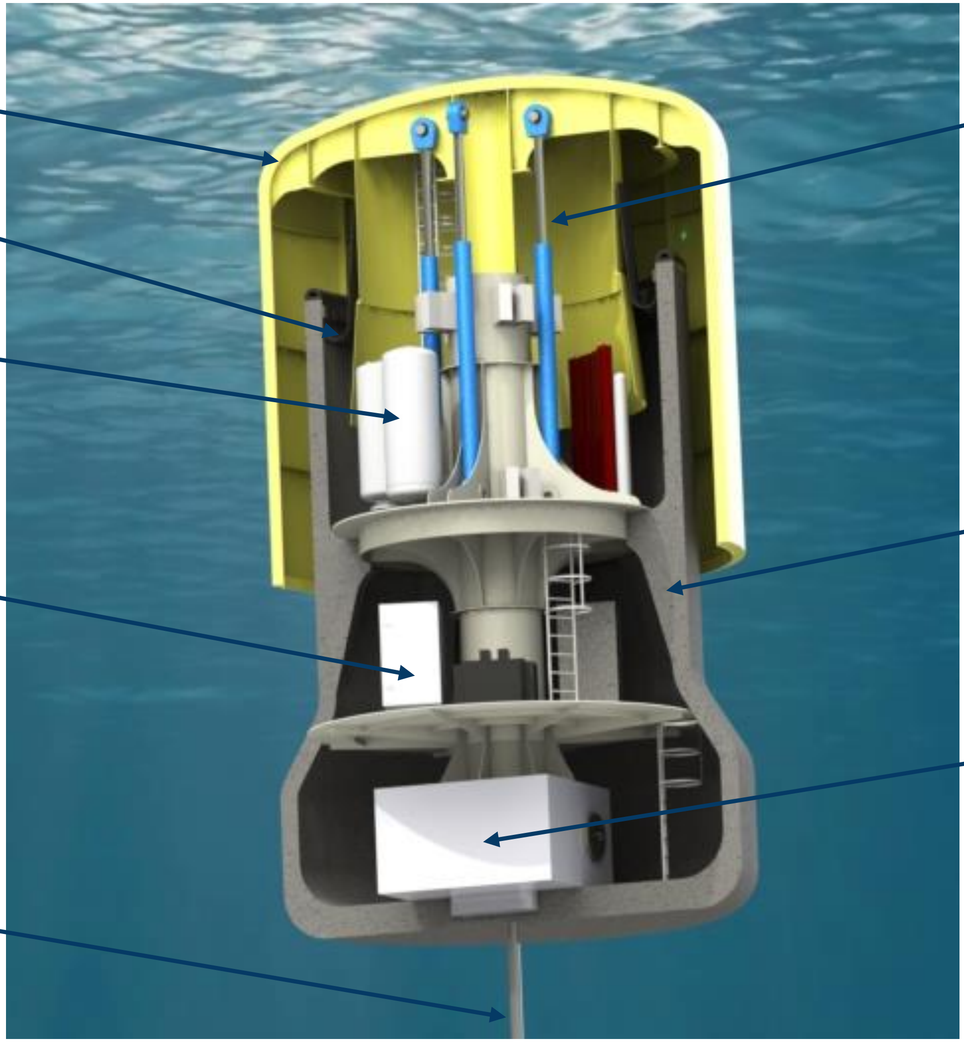
WES Annual Conference 2018

Simon Grey

Stage 2 project outcomes

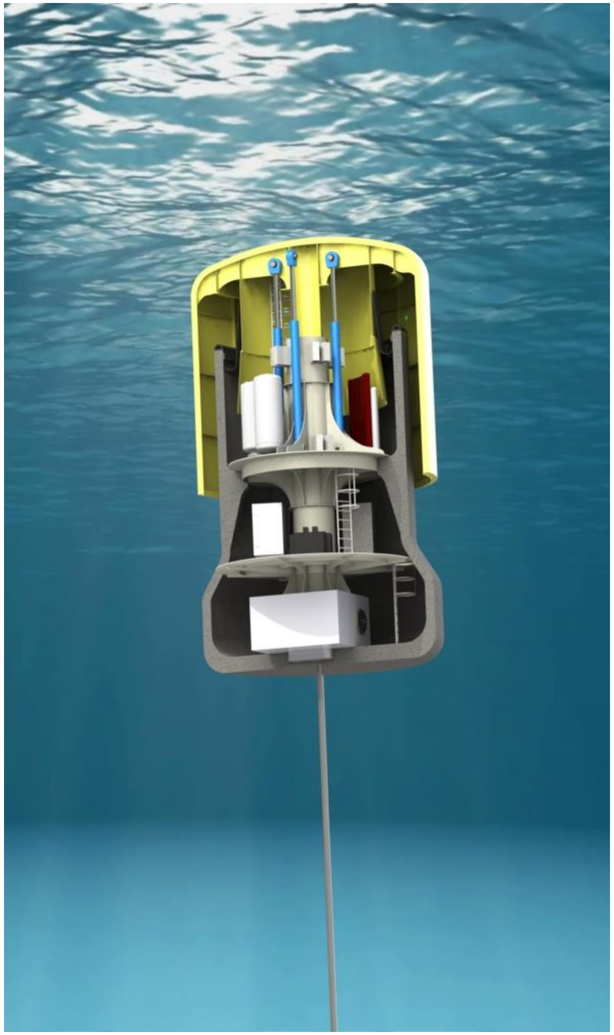
- > 3X increase in performance
- Full validation of numerical performance model
- Feasible full-scale solutions identified for all sub-systems
- Further structural and cost optimisation
- Full technical risk analysis to set basis for the technology qualification programme
- FEED completed for half-scale at-sea technology demonstrator
- Marine operations for deployment and recovery developed and confirmed as safe and practical by third-party experts
- Stage 3 project fully defined, costed and ready to start!

Waveswing explained



Current expected performance - commercial

- 250 kW rated continuous output
- 8.0m diameter floater with 3.0m stroke
  - ~ 55 ton of structural steel
- 832 MWh/year in 33kW/m achievable
  - Raw capture factor approaching 50%
  - 7.3 MWh mechanical energy per m^3 of swept volume
  - 20 MWh / ton of structural steel
- FOAK demonstration project cost ~ £5.0 million
- Long term LCOE £150/MWh in 33kW/m
  - Or better in more energetic resource



Key lessons learned

- Theoretical power limit for Waveswing is 2X that for floating point-absorber
- Optimal control does not need future knowledge of wave
- High natural frequency of the absorber can be advantageous when using smart control
- Hydraulics provide the most cost-effective and capable PTO solution with all functional and performance requirements met
- Being subsea does not preclude rapid recovery and an effective maintenance strategy with high availability
- Achieving cost-competitiveness with offshore wind is possible with 1GW of installed capacity

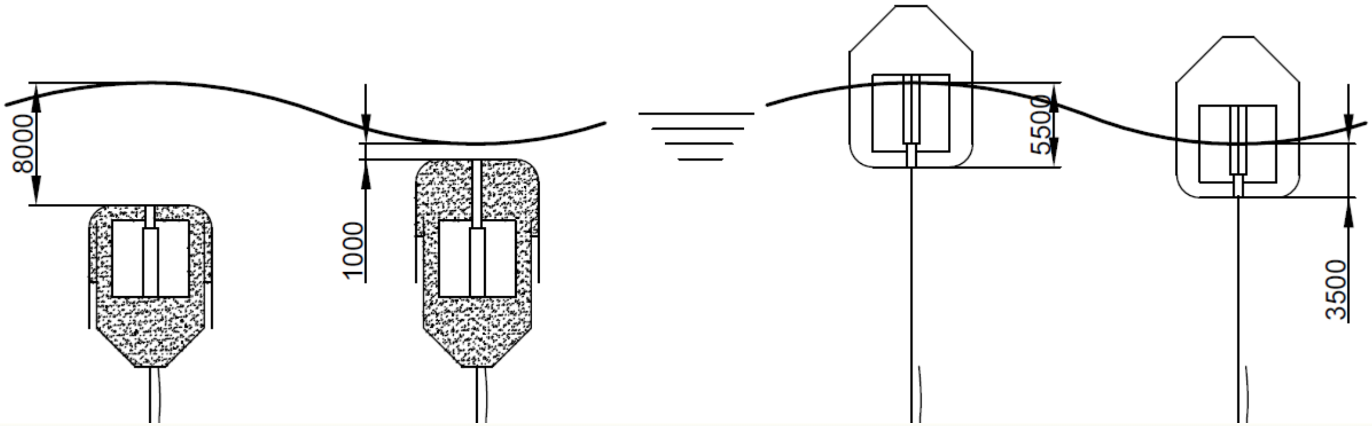
Waveswing fundamentals

- Power per unit volume double surface-piercing devices
  - Wave forcing from pressure – double the power of equivalent floating device

$$\boldsymbol{Surface\ piercing}:\ P/V = \frac{\rho g \pi A}{2T}$$

  - Waveswing amplitude of motion not constrained to half wave amplitude so limit doubles!

$$\boldsymbol{Waveswing}:\ \frac{P}{V} = \frac{\rho g \pi A}{\not{2}T}$$

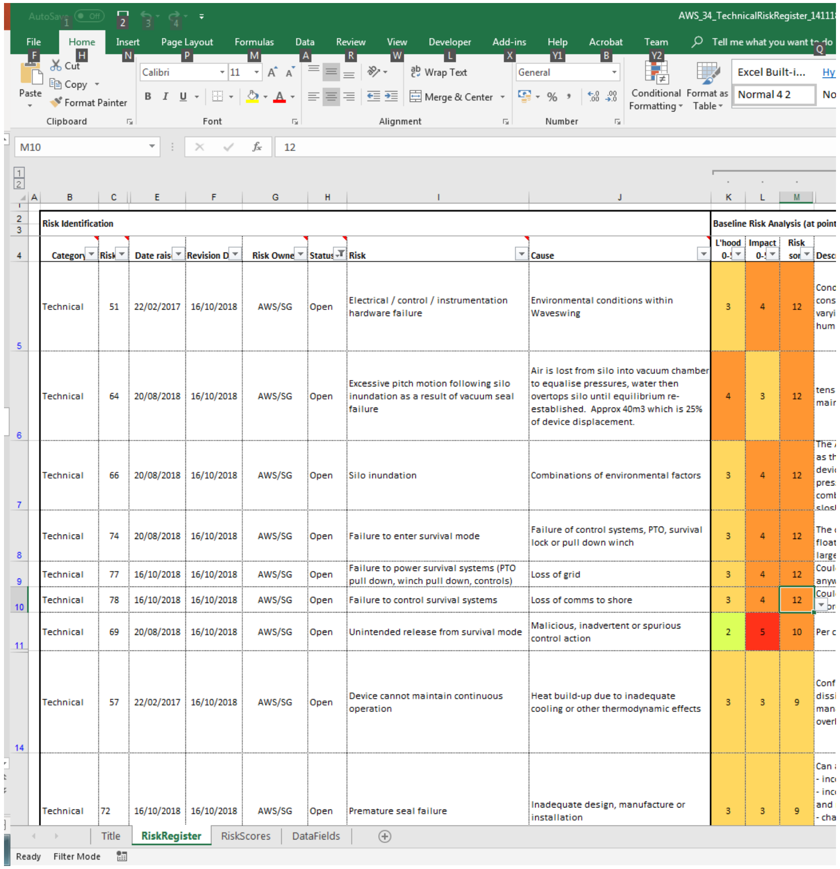


Technology advantages

- Potential for best in class LCOE due to fundamentals
- Can be scaled to 500kW for single device and combined on multi-MW platforms
- Survivability & safety – shut-down and hide from waves
- Zero visual impact – may be issue in early markets
- High power density (low use of real-estate)
- Low impact on fishing due to single-point moorings
- Self deploying – only requires tow to/from site with local vessels
- Major fabrications and marine ops can be local
- Key technology can be packaged for export (from Scotland)

Technology risk

- Key technical uncertainties that will affect the long-term viability of the technology:
  - Longevity of rolling seal
  - Performance of PTO
  - Effect of biofouling
  - Unforeseen deployment / recovery issues
  - Device loads and stability as volume is reduced
- Engineering risks – challenges to be overcome by good design
  - Durability and longevity of sensors in harsh environment
  - Functionality and reliability of survival systems
  - Functionality and reliability of internal pressure control
  - General system reliability and availability



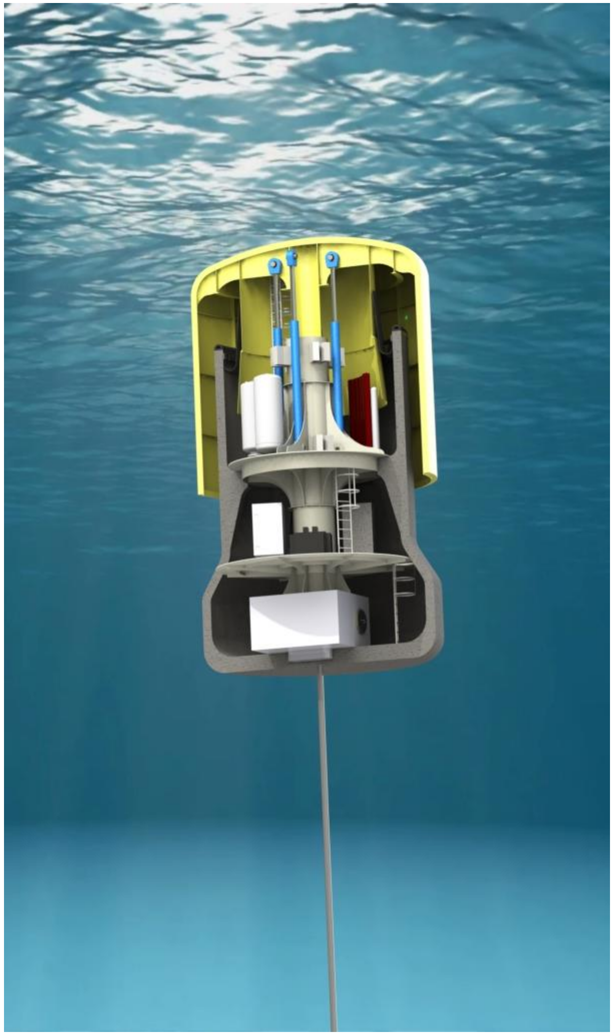
Risk Identification								Baseline Risk Analysis (at point		
Category	Risk	Date rais	Revision D	Risk Owne	Status	Risk	Cause	L'hood 0-!	Impact 0-!	Risk sor
Technical	51	22/02/2017	16/10/2018	AWS/SG	Open	Electrical / control / instrumentation hardware failure	Environmental conditions within Waveswing	3	4	12
Technical	64	20/08/2018	16/10/2018	AWS/SG	Open	Excessive pitch motion following silo inundation as a result of vacuum seal failure	Air is lost from silo into vacuum chamber to equalise pressures, water then overtops silo until equilibrium re-established. Approx 40m3 which is 25% of device displacement.	4	3	12
Technical	66	20/08/2018	16/10/2018	AWS/SG	Open	Silo inundation	Combinations of environmental factors	3	4	12
Technical	74	20/08/2018	16/10/2018	AWS/SG	Open	Failure to enter survival mode	Failure of control systems, PTO, survival lock or pull down winch	3	4	12
Technical	77	16/10/2018	16/10/2018	AWS/SG	Open	Failure to power survival systems (PTO pull down, winch pull down, controls)	Loss of grid	3	4	12
Technical	78	16/10/2018	16/10/2018	AWS/SG	Open	Failure to control survival systems	Loss of comms to shore	3	4	12
Technical	69	20/08/2018	16/10/2018	AWS/SG	Open	Unintended release from survival mode	Malicious, inadvertent or spurious control action	2	5	10
Technical	57	22/02/2017	16/10/2018	AWS/SG	Open	Device cannot maintain continuous operation	Heat build-up due to inadequate cooling or other thermodynamic effects	3	3	9
Technical	72	16/10/2018	16/10/2018	AWS/SG	Open	Premature seal failure	Inadequate design, manufacture or installation	3	3	9

Next steps

- WES NWEC 3 project to demonstrate and de-risk technology:
    - Half-scale prototype to be deployed at EMEC nursery site in 2020
    - Fully functional WEC containing all sub-systems as per full-scale design
    - Test and demonstrate PTO function
    - Test and demonstrate rolling seal
    - Test and demonstrate deployment / tidal compensation systems
    - Demonstrate and refine marine operations
    - Collect data for load and performance model validation
    - Gain experience ahead of design of FOAK

Summary

- Highly successful project delivering significant advancement of technology
- Best-in-class performance underpinned by fundamental physics
- Engineering of commercial system fully feasible
- Confident that remaining technology risks can be met in Stage 3
- Excellent team-work – thank you!
- Looking forward to Stage 3 demonstration and engaging with potential investors

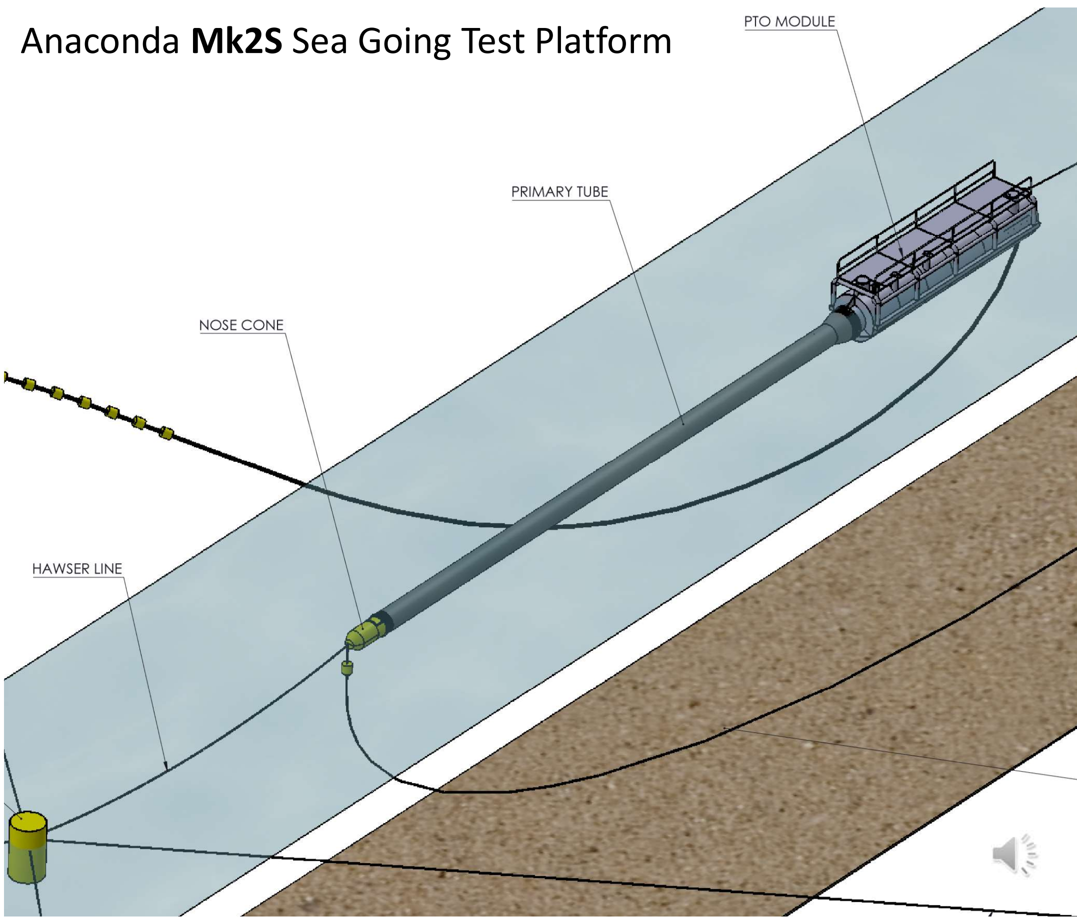


Anaconda Mk2
CHECKMATE
SEA ENERGY ANACONDA
SHAPING THE FUTURE OF WAVE ENERGY
wave energy
SCOTLAND
EGI GROUP
Quoceant
Innovation Offshore
BLACK & VEATCH
Rubber Consultants
TESTING • INNOVATION • SOLUTIONS
EMEC ORKNEY
THE EUROPEAN MARINE ENERGY CENTRE LTD
FENNER DUNLOP
ENGINEERED CONVEYOR SOLUTIONS
University of Strathclyde Glasgow
FloWave
LiR
NATIONAL OCEAN TEST FACILITY
LEASK MARINE

Anaconda Mk2 – Breakthrough Potential

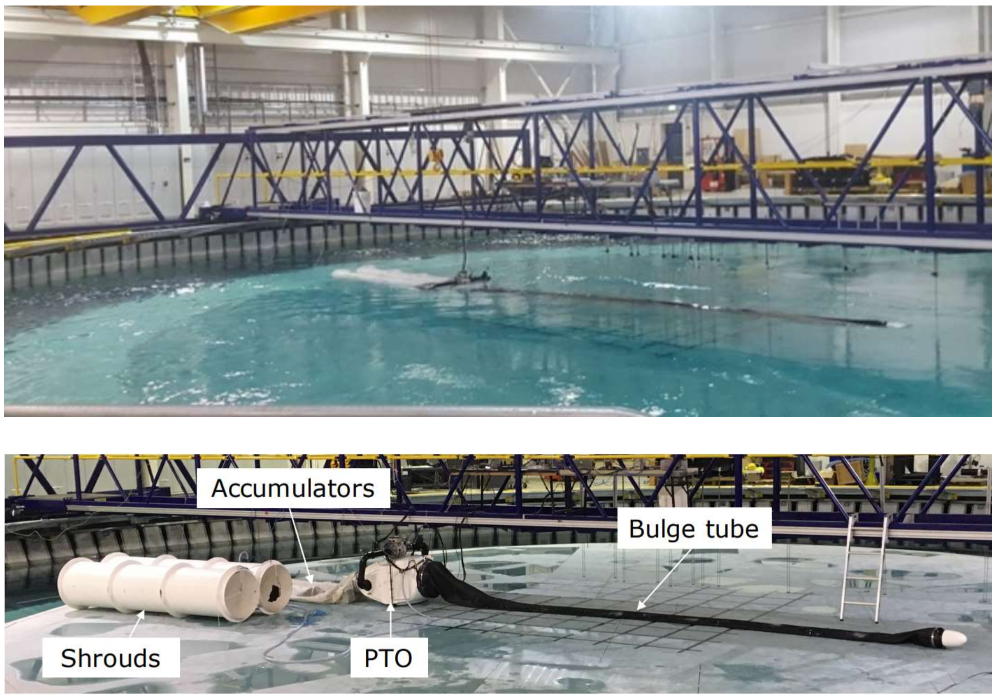
1. "Continuum" Absorber: independent of PTO
2. Self-referencing, based on flexible materials. Integrity independent of absorber structure
3. Operations: Low-draft, horizontal orientation
4. Unique Scaling with further "step change" learning opportunities

Anaconda **Mk2S** Sea Going Test Platform



STAGE 2 DEVELOPMENTS

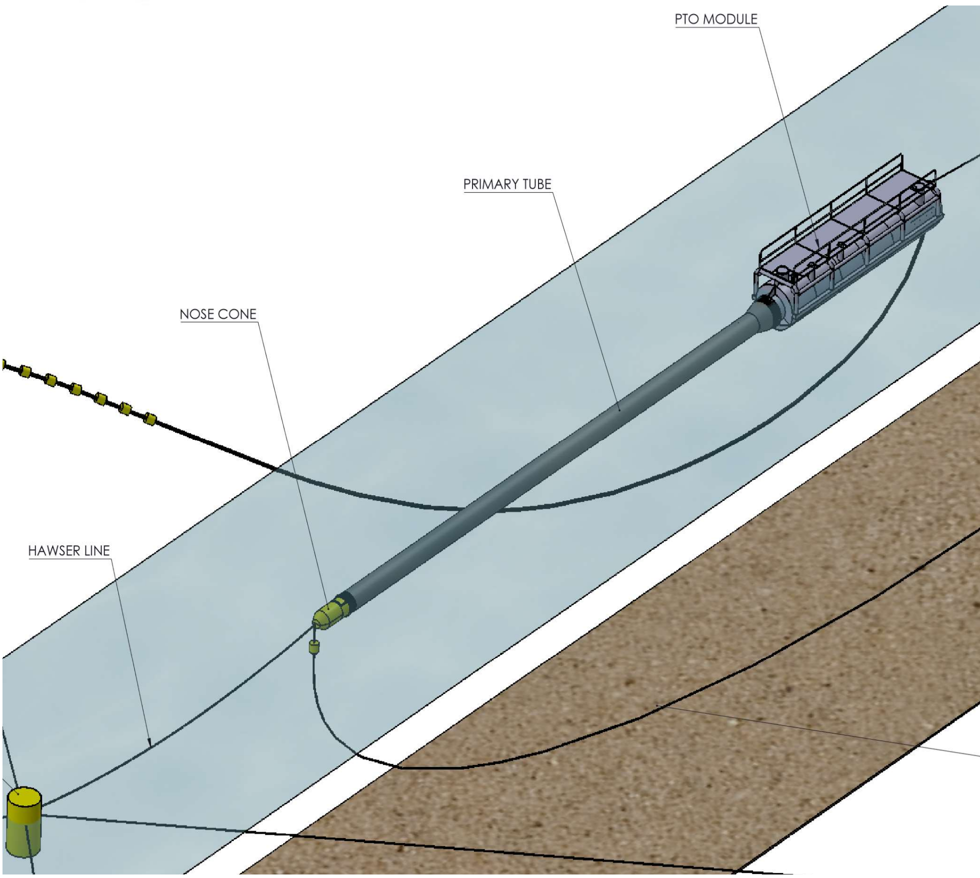
Concept Iteration Mk1 to Mk2

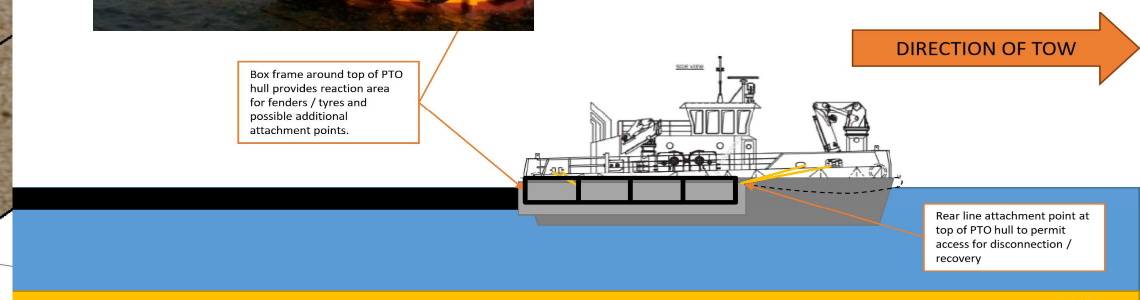


Mk1 Tests (Strathclyde, Flowave, Lir)

Mk2 Tests (Strathclyde, Lir)

Stage 3 Proposal





CONTACT US

Thank You!

http://www.checkmateukseaenergy.com/contact/

Mocean WEC: Next-level Hydrodynamics and Engineering

mocean energy

BLACKFISH

ECOSSE Subsea Systems ...because we think differently

SUPPLYDESIGN

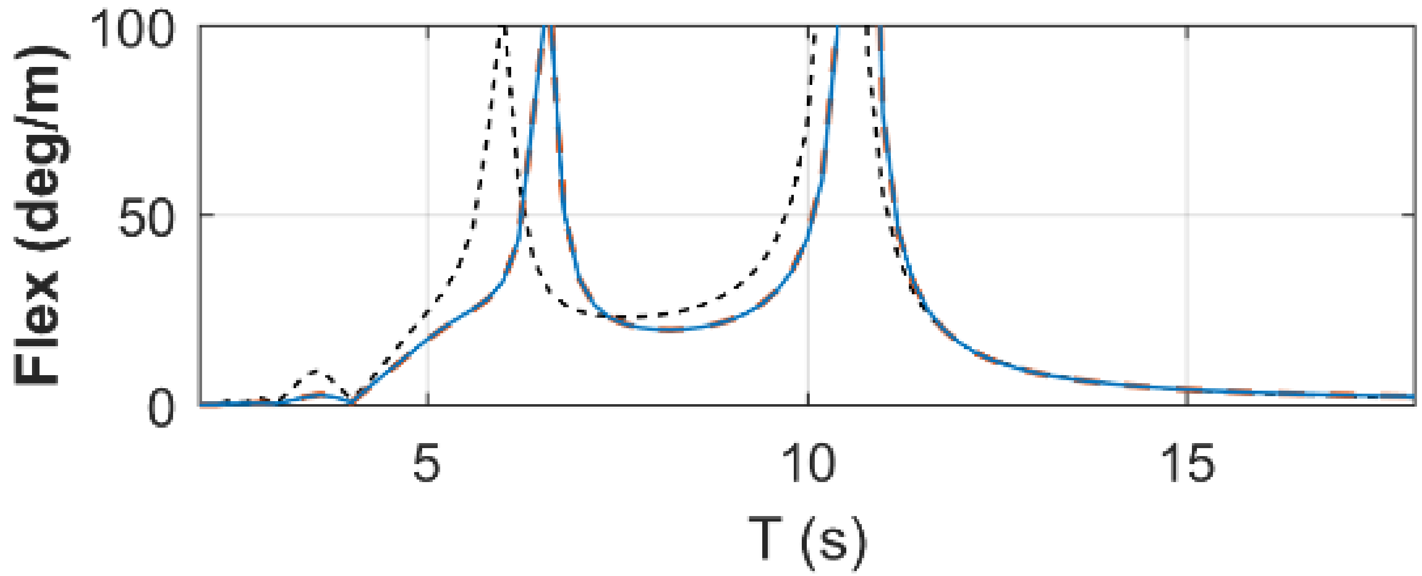
BEDL Bathwick Electrical Design Ltd

industrial systems and control

Performance

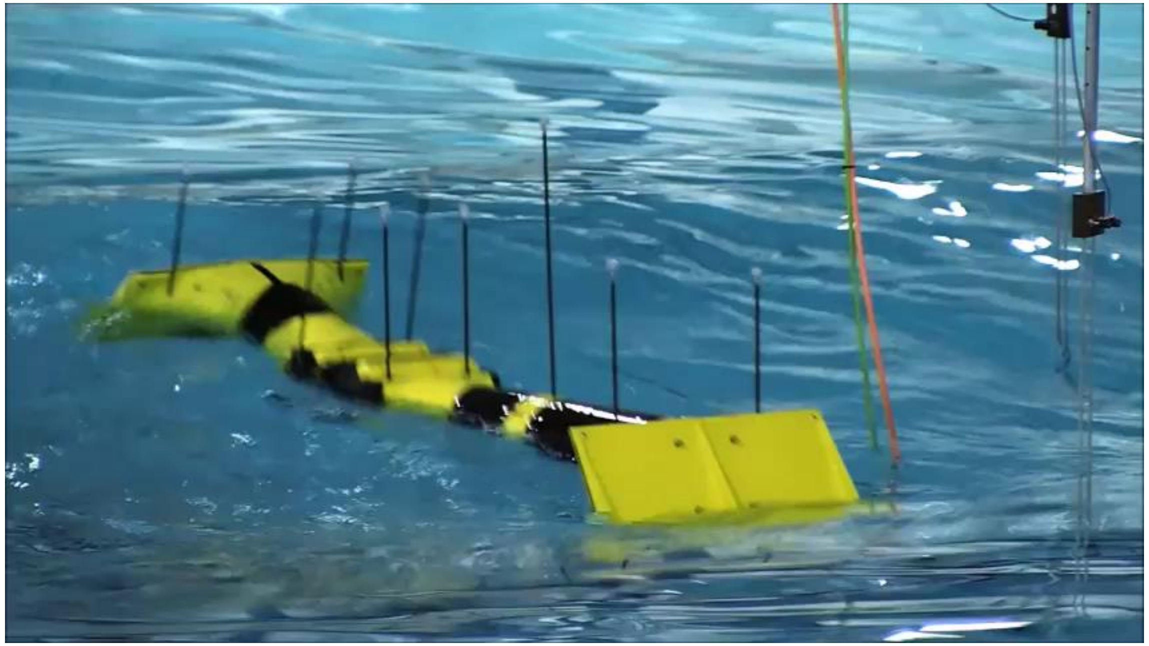
- Geometry induces high excitation force per unit mass
- DoF cross-coupling and wave channels broaden bandwidth – resonances at 2x and 5x WEC length
- Well-validated numerical model – further increases in performance expected

Undamped resonant response



Survival

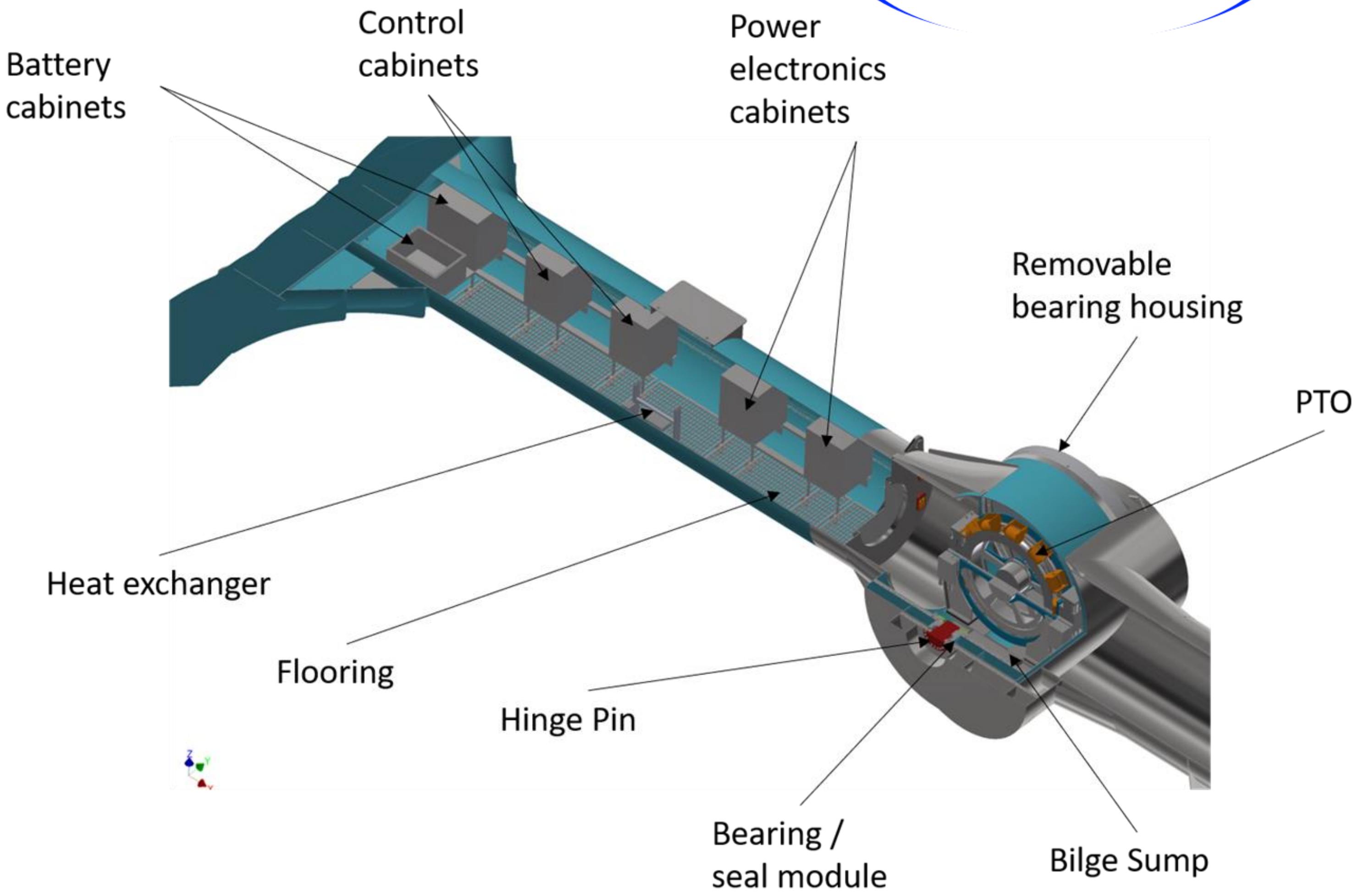
- Steep waves overtop the WEC
- Rotary PTO has infinite rotation
- Maximum hinge rotation (currently 90°) limited only by clash of hulls
- Damped compliant fender absorbs residual energy
- Unconditional roll stability
- No slam forces



Overtopping in steep waves

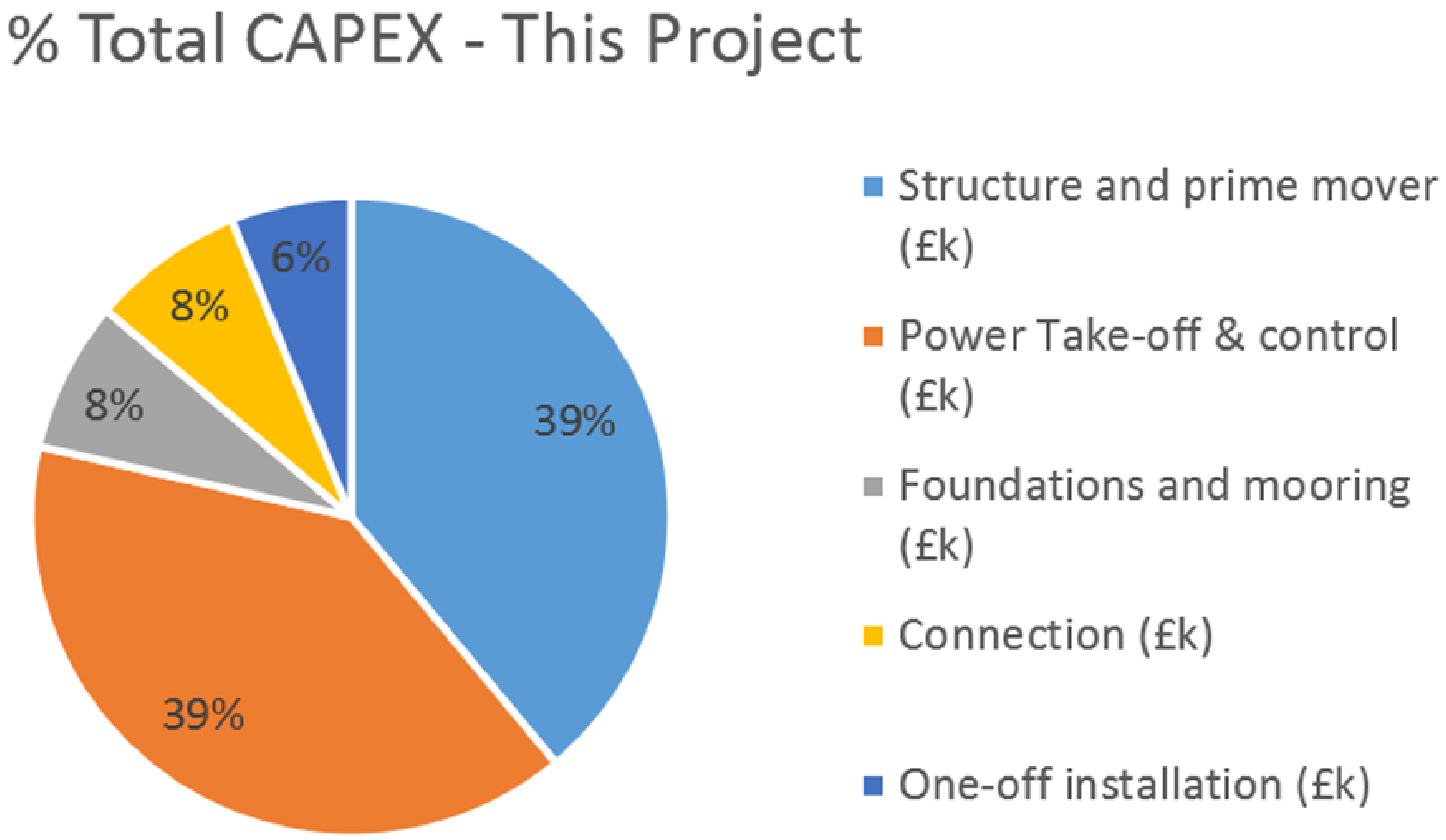
Reliability

- Single hinge, single DoF, integrated bearings & seals
- Non-contact magnetic gear
- All electric PTO, low parts count
- Redundancy from multiple generators
- WEC self-referenced, reduced mooring forces
- Sealed aft section – no cable transits



Affordability

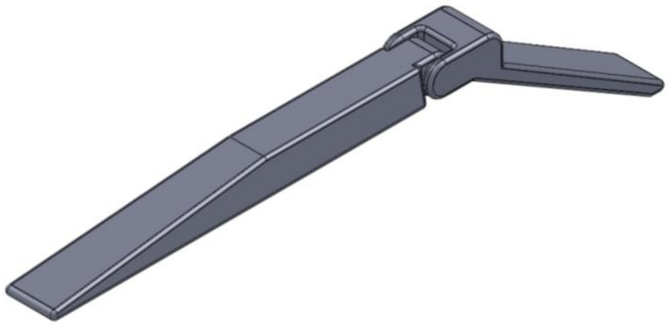
- Bulk of cost is for structure and PTO (torque)
- 45% less structural mass per power than NWEC1
- 66% lower torque per power than NWEC1
- All-electric PTO will leverage advances in solar, wind and vehicle markets (batteries, power electronics, control)



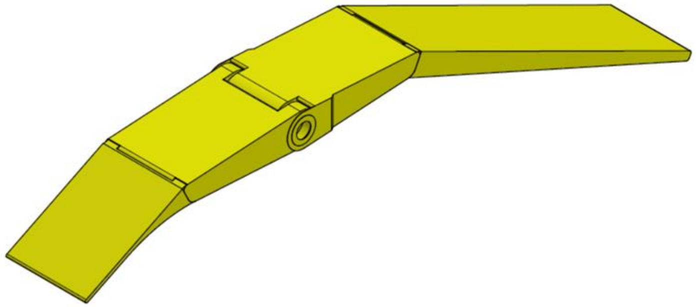
Mocean WEC Evolution

step-change improvements at each NWEC stage.

NWEC Application



NWEC Stage 1



Advanced geometrics in numerical optimisation

Identified issue with model validation

50% increase in mean power/mass

NWEC Stage 2

Added nonlinear spectral modelling.
Added torque cost to optimisation

Initial working model of wave channels

Reduced draft, improved manufacturability

Further 80% increase in mean power/mass
3x improvement in power/torque

WES Annual Conference 2018

Project Progress Updates: Power Take-Off, Stage 3

File Contents

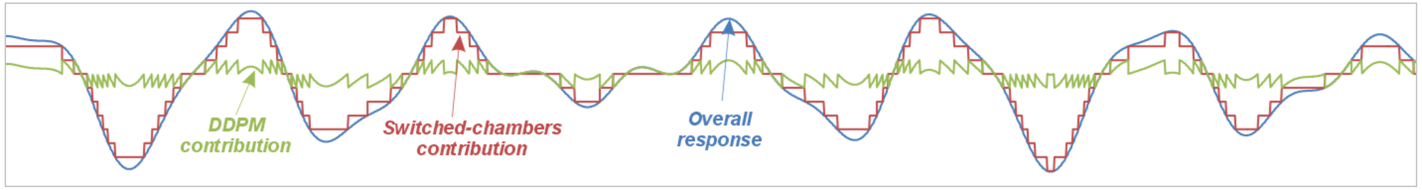
- Artimus – Quantor Hybrid Hydraulic PTO [10 pages]
- Oceaneering – Power Electronic Controlled Magnetic Gear [5 pages]
- Umbra Group – Electro-Mechanical Reciprocating Generator [14 pages]
- University of Edinburgh – Project Neptune [12 pages]

Wave Energy Scotland Annual Conference, 8 December 2018
Elevator Pitches

Quantor hybrid hydraulic PTO – Stage 3

Lead Contractor: Artemis Intelligent Power

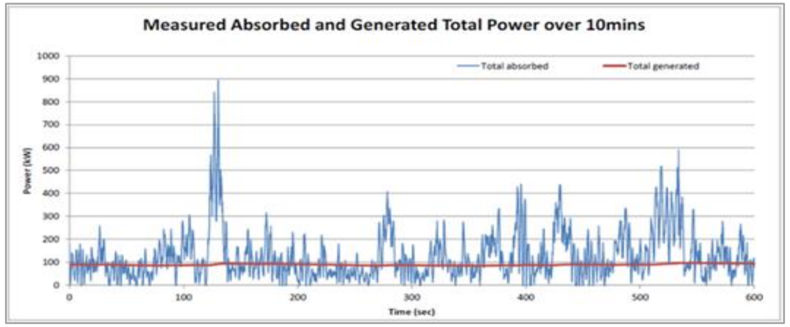
Sub-contractor: Quoceant



Presenter: Jamie Taylor, Artemis

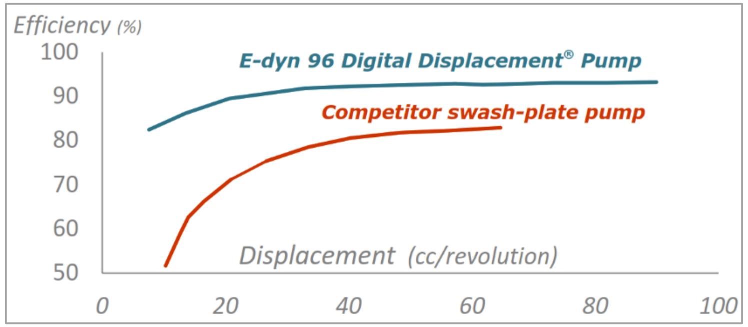
Quantor - Combination of ‘Quantised’ & Digital Displacement® (DD) systems

Pelamis with Quantised hydraulic PTO



Ocean-proven, high WEC to wire efficiency and steady power to grid.

Rail vehicle with Digital Displacement hybrid drive



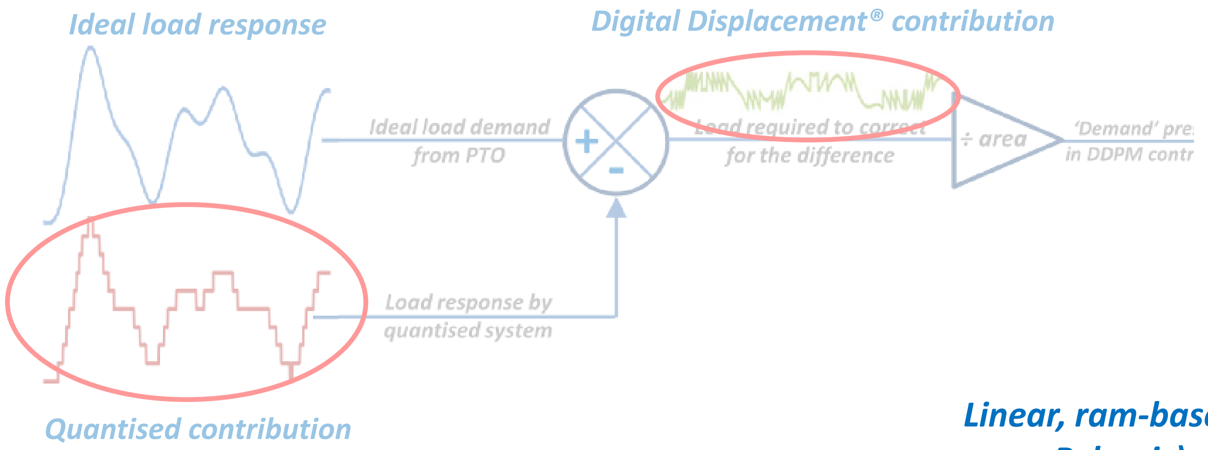
Generic hydraulic machines with high efficiency and controllability.

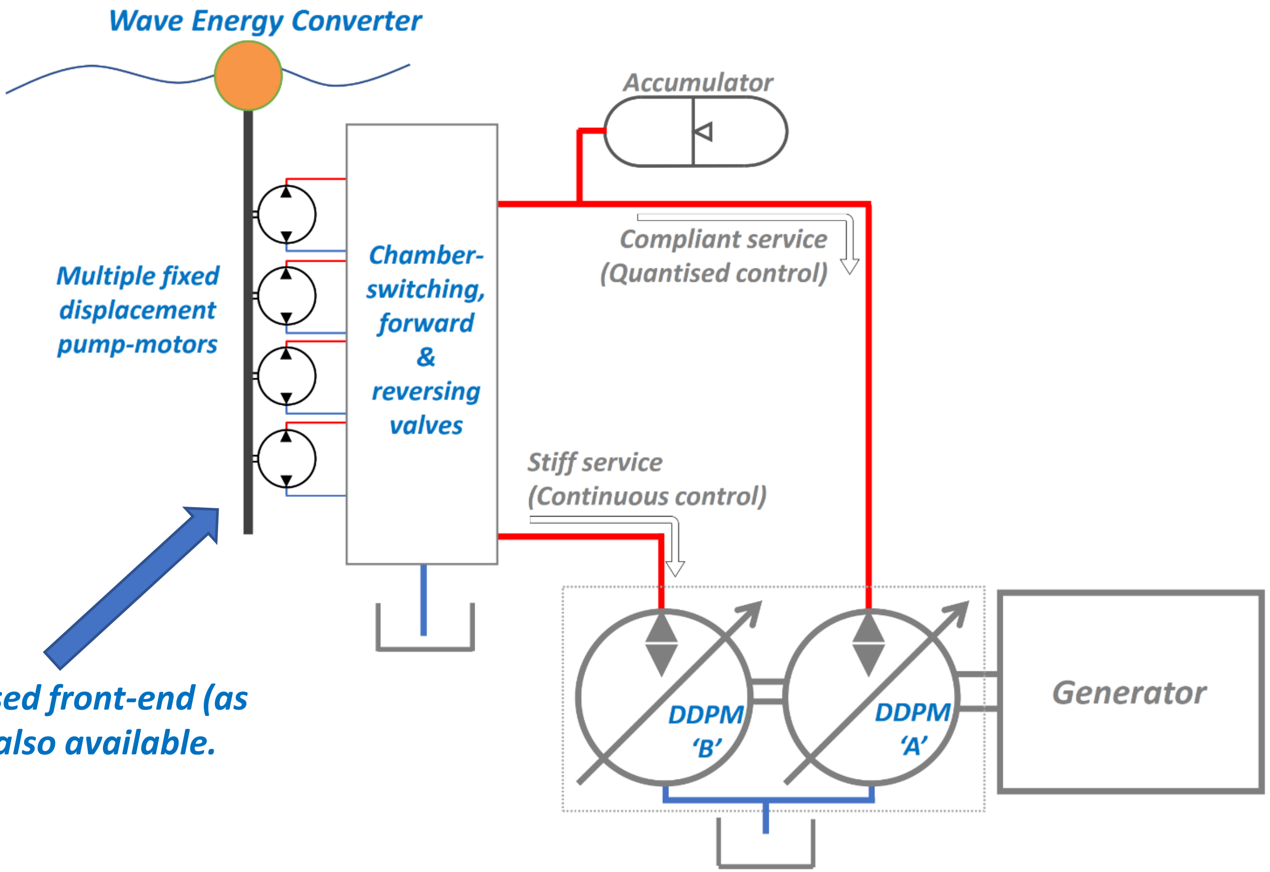
Quantor aim: *improve hydrodynamic controllability of WEC and hence increase energy captured from it.*

ARTEMIS INTELLIGENT POWER

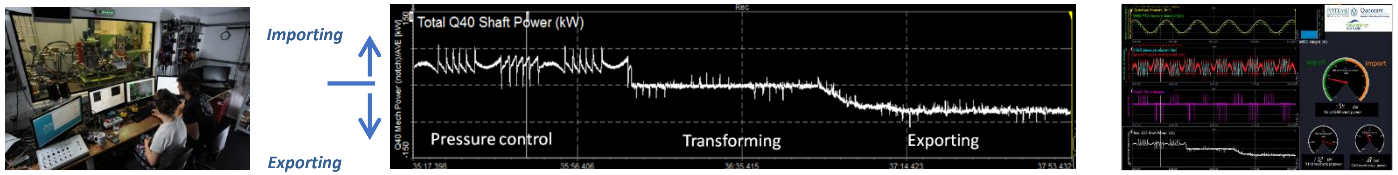
Quoceant

Quantor – How it works





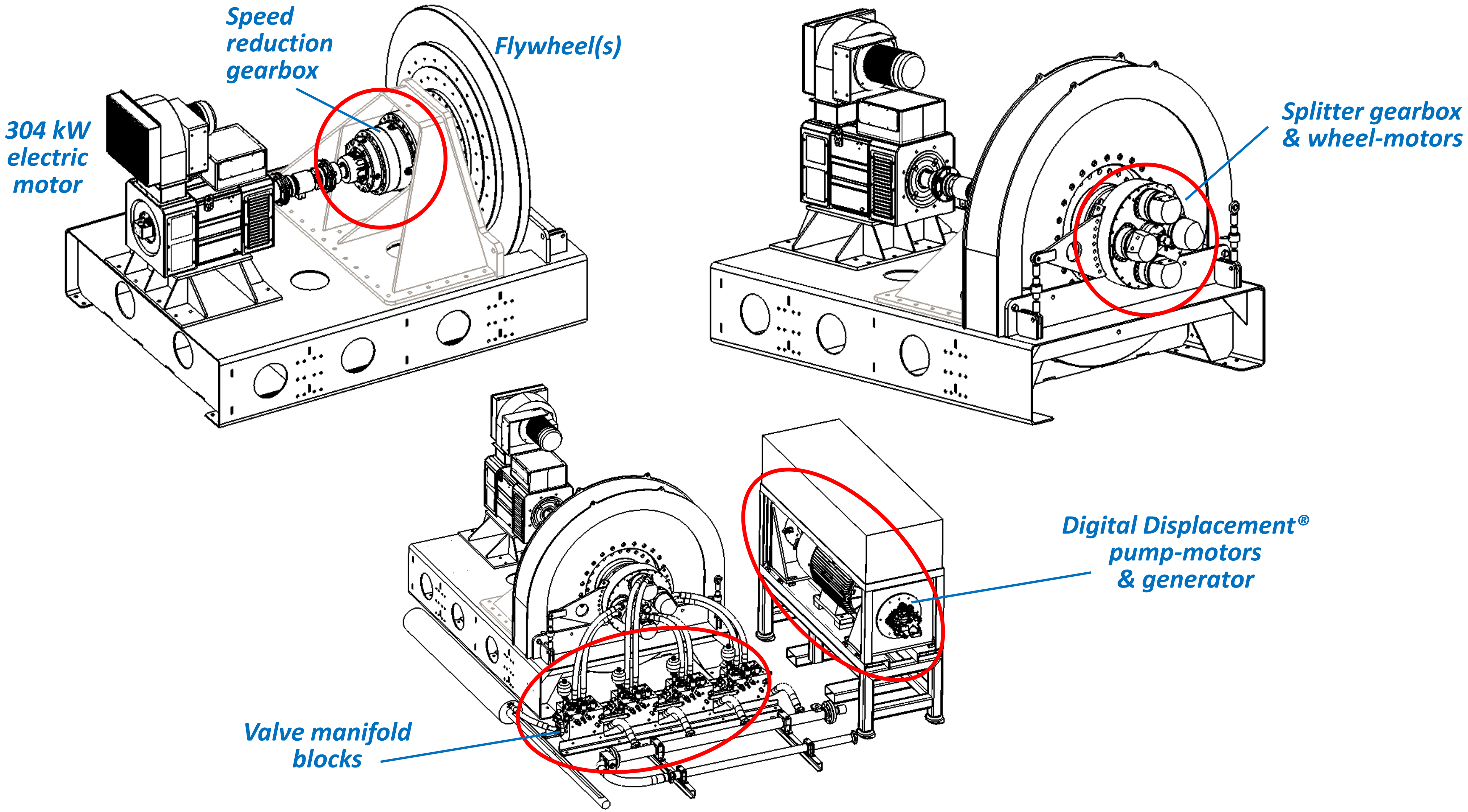
Linear, ram-based front-end (as per Pelamis) also available.



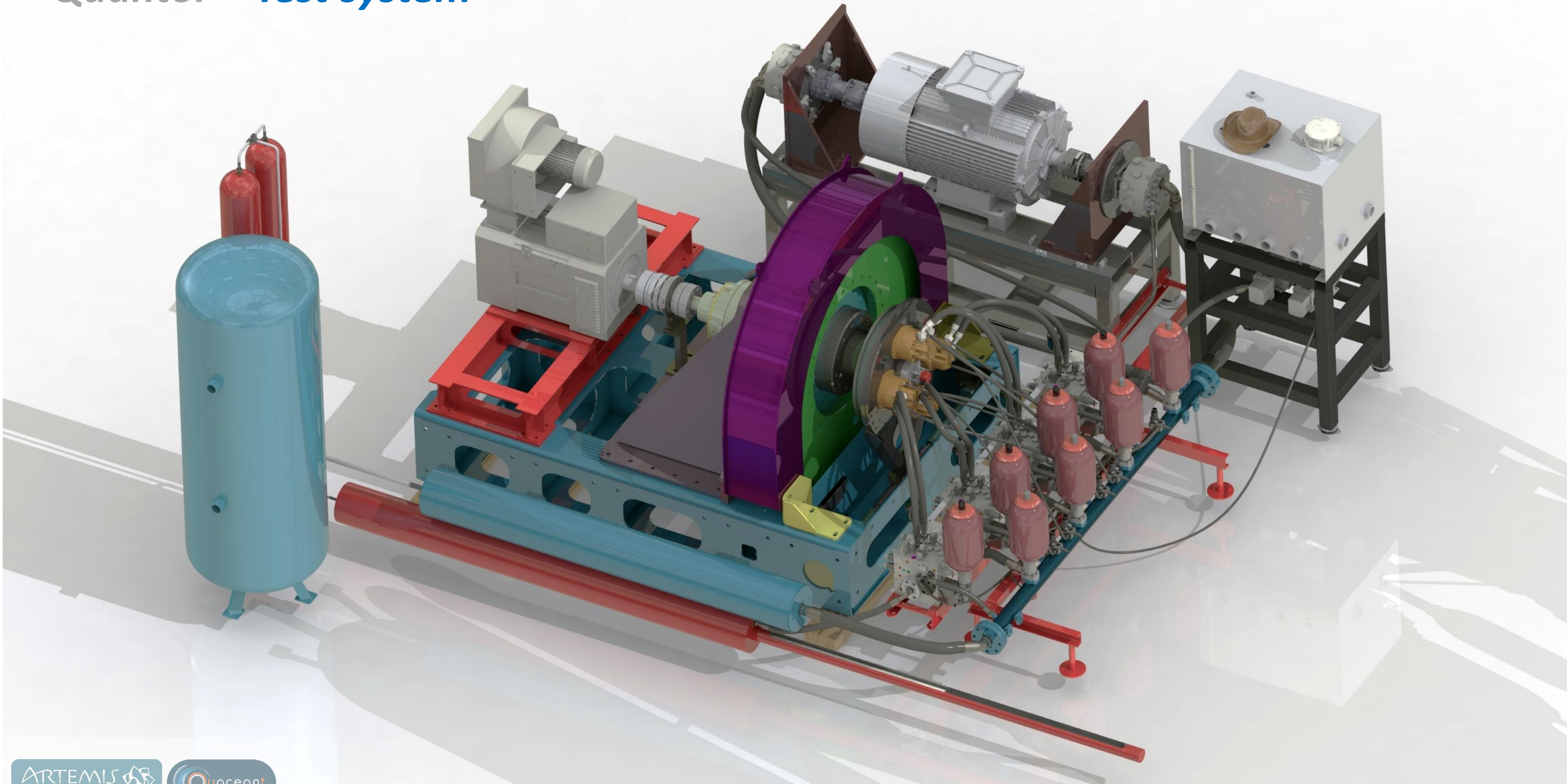
Stage 2 project demonstrated the technical feasibility

ARTEMIS INTELLIGENT POWER
Quocean

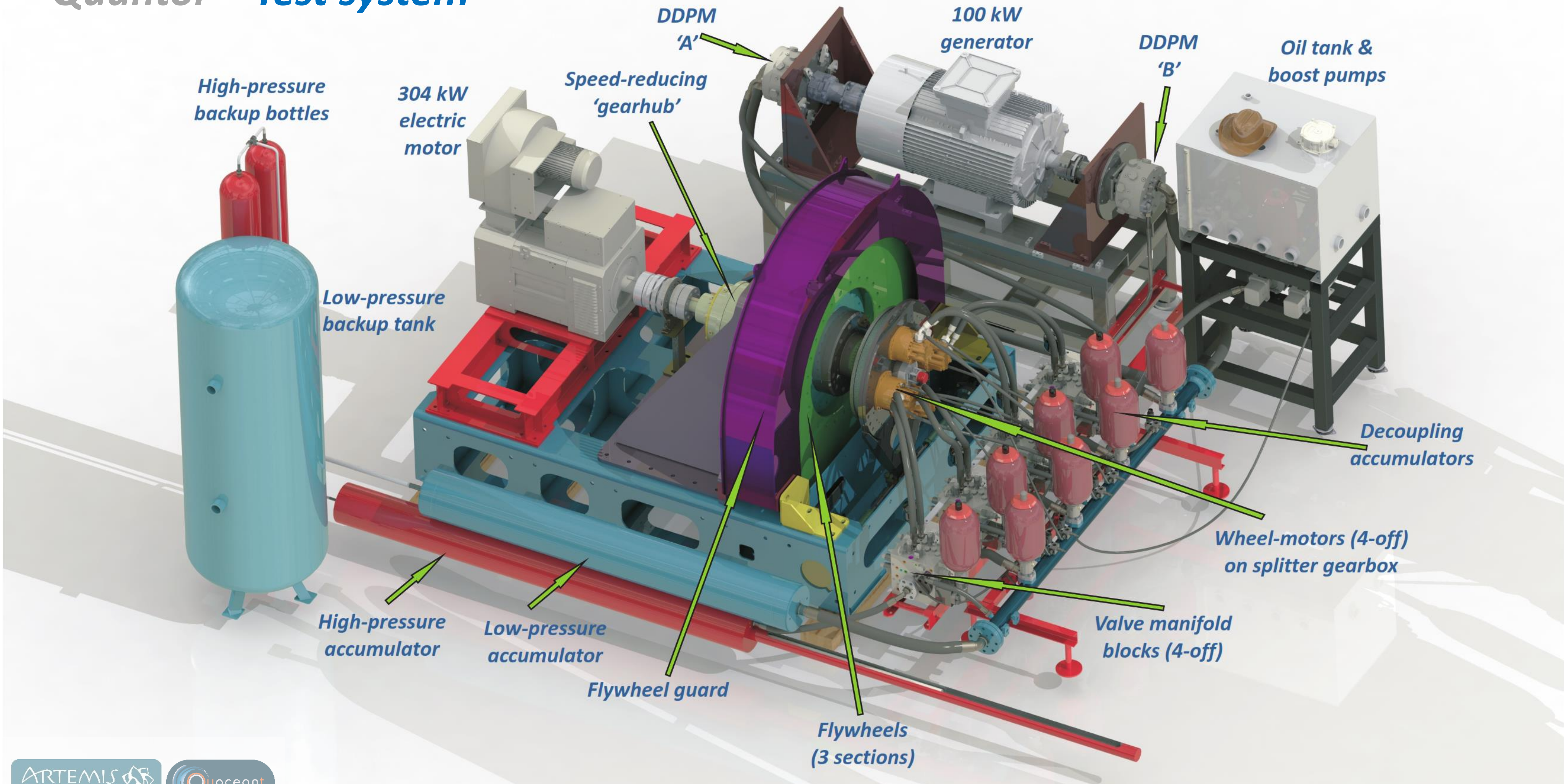
Quantor – Test system



Quantor – Test system



Quantor – Test system

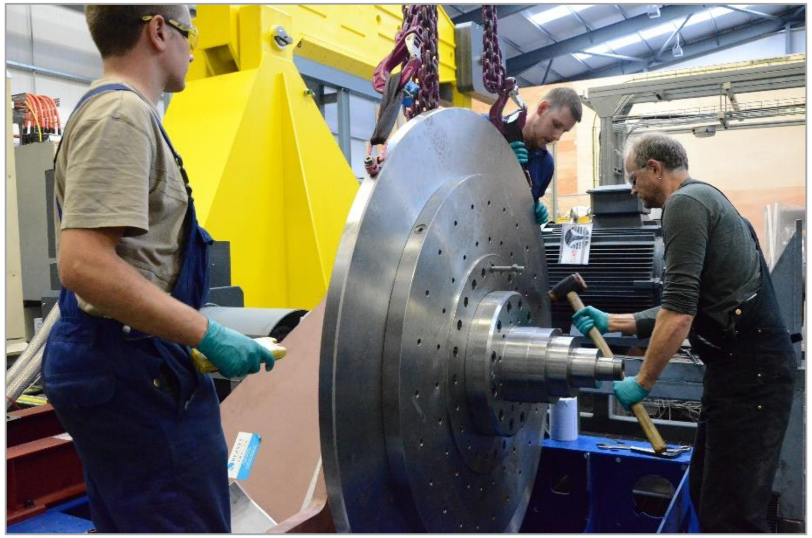


ARTEMIS INTELLIGENT POWER

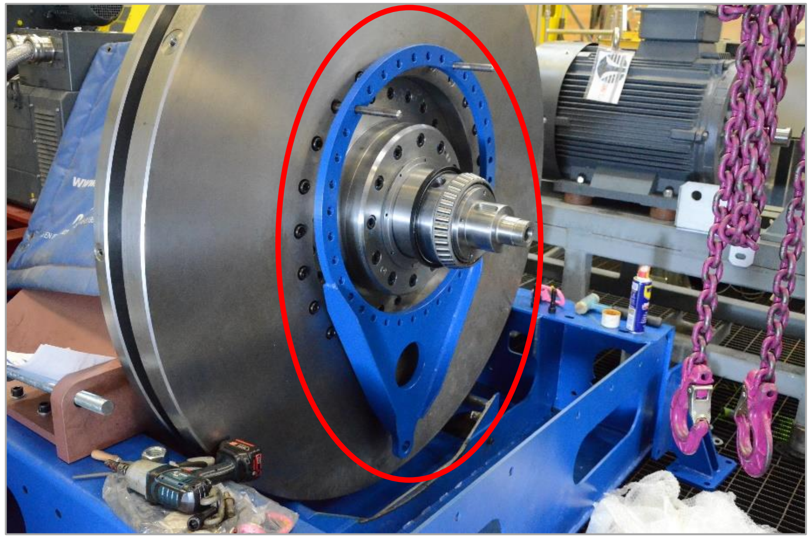
Quoceant

Quantor – Flywheel & gearbox

Flywheel preparation

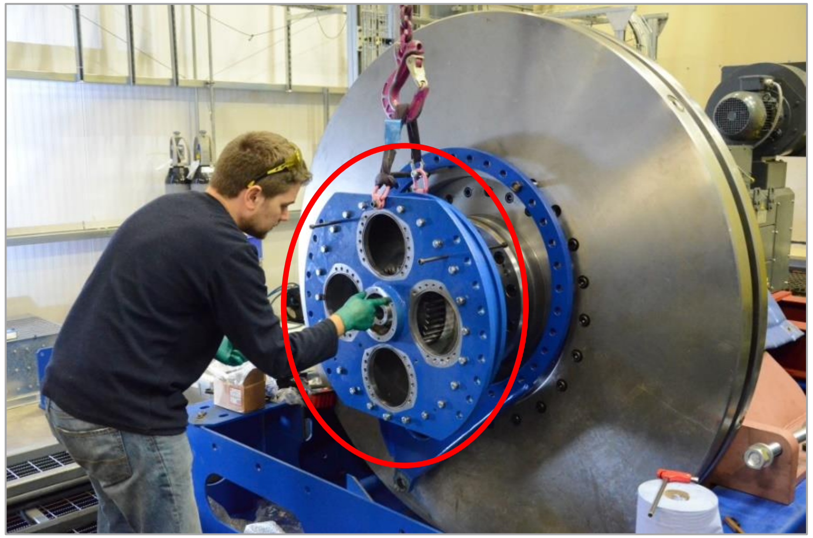


Flywheel installation

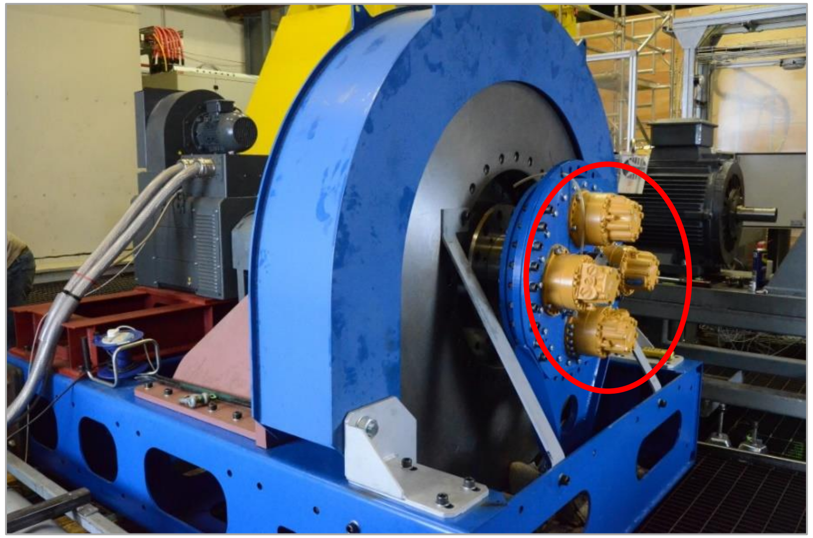


Torque arm

Drive motor, gearbox & flywheel guard



Assembly of splitter gearbox

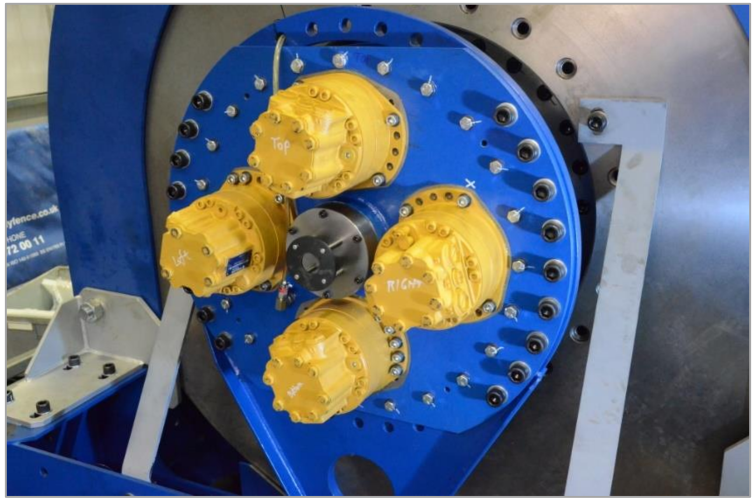


Wheel motors in position

ARTEMIS INTELLIGENT POWER

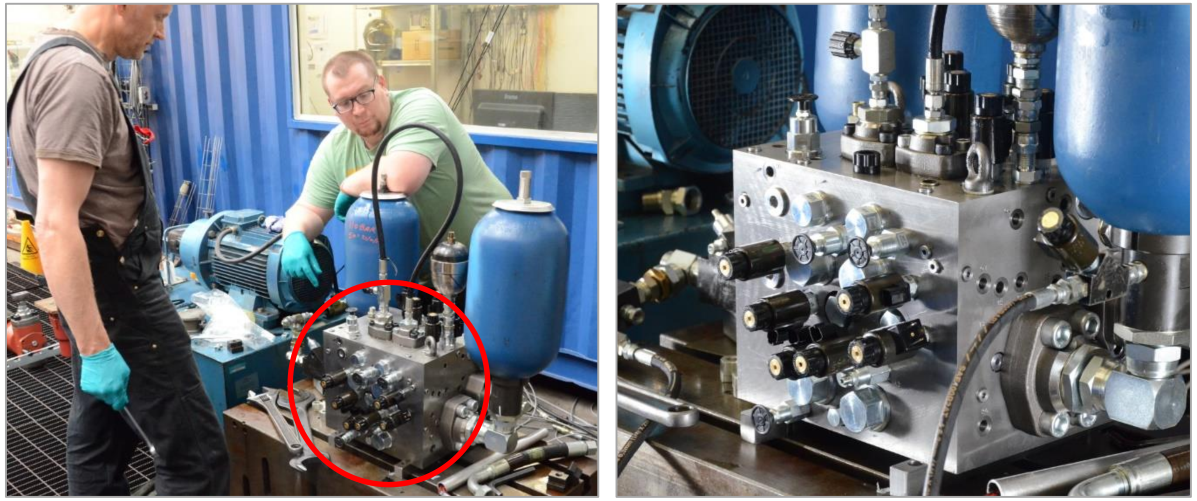
Quoceant

Quantor – Wheel-motors, manifold blocks & DD pump-motor

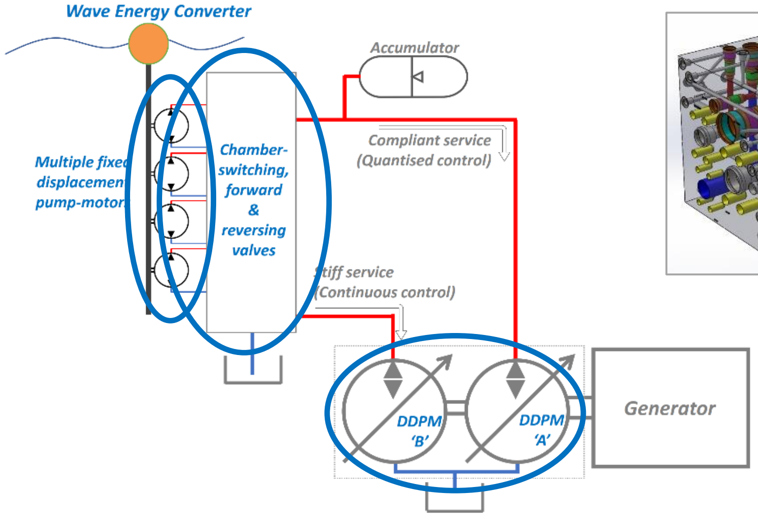


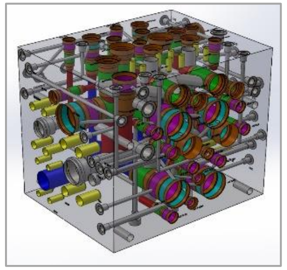
Four wheel-motors

Poclain MS02

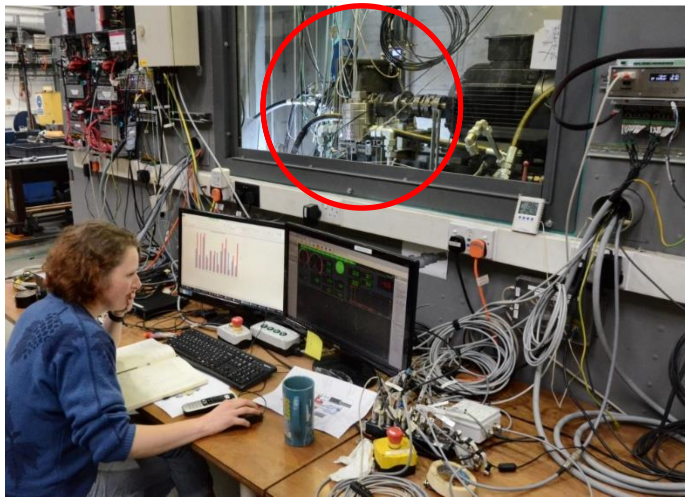


Prototype manifold block





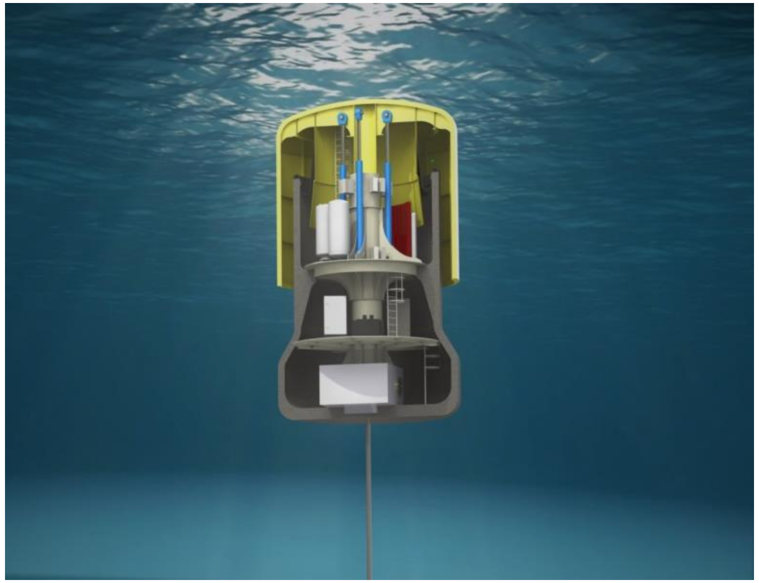
Artemis 'M96' pump-motor



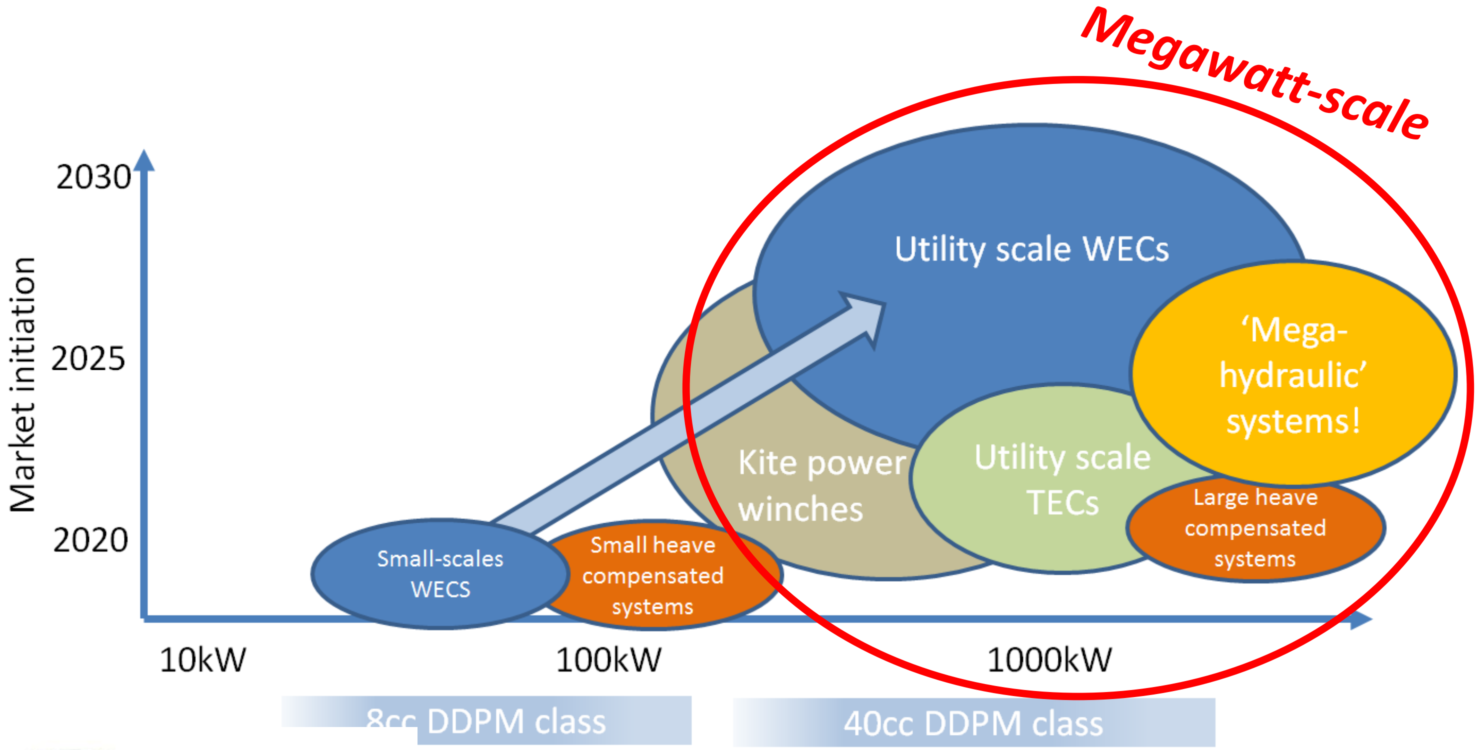
Testing 'M96' pump-motor

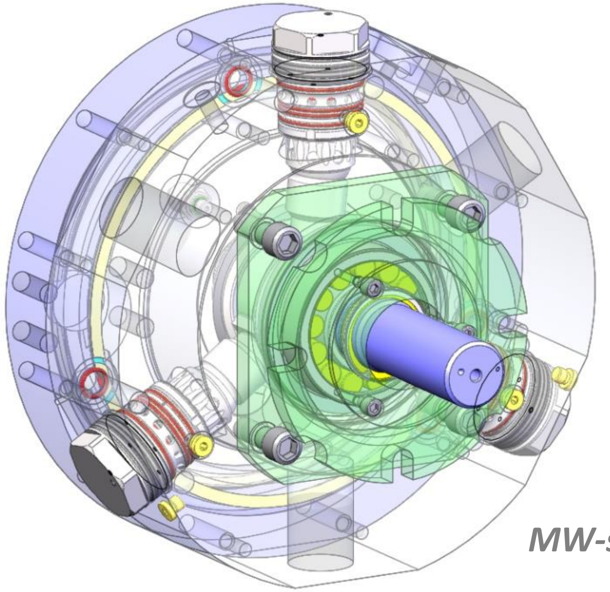
ARTEMIS INTELLIGENT POWER
Quoceant

Quantor – Exploitation



WEC with linear variant of Quantor
(Courtesy: AWS Ocean Energy)





MW-scale prototype DD pump-motor

[*www.artemisip.com*](http://www.artemisip.com)

[*www.quoceant.com*](http://www.quoceant.com)

OCEANEERING®

Stage 3 PTO: PECMAG

WES 3rd Annual Conference, Edinburgh, 6th December 2018

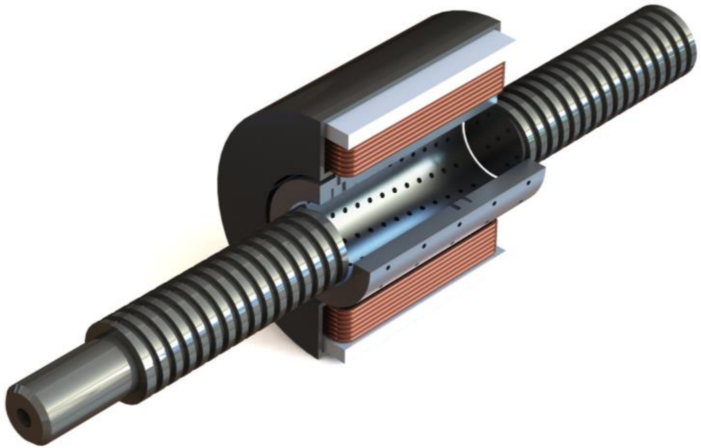
Mark Brown, Engineering Manager - Renewables & Subsea Projects (Europe)

PECMAG

|POWER ELECTRONIC CONTROLLED MAGNETIC GEAR|

All electric system; magnetic gear and generator coupled to an integrated power and control system.

- **Integrated system|** Gear, generator, power electronics and control system developed as a single package
- **Improved Survivability|** Non contact gear allows damage free slippage in extreme sea states
- **Leading Efficiency|** Gear enhanced by highly configurable power system to maximize capture efficiency
- **Increased Availability|** Redundant configurations to enable degraded system availability



OCEANEERING® BEDL Bathwick Electrical Design Ltd SUPPLYDESIGN BESPOKE ELECTRONICS Pure Marine

Stage 3 Project

|SCOPE|

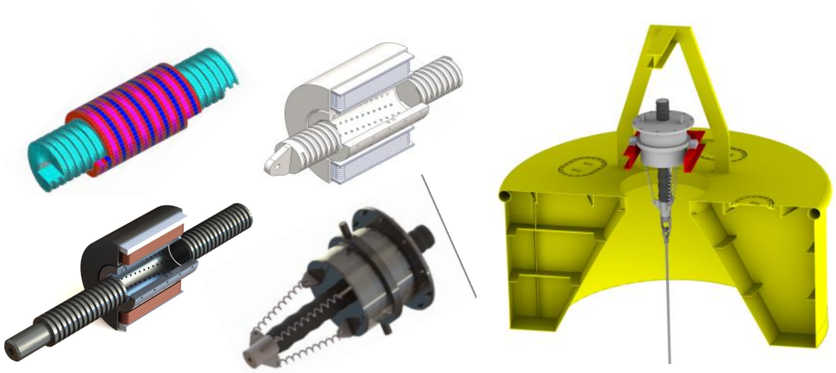
- Develop 10kW linear to rotary system
- Design & manufacture gear, generator, power system, in water test platform and monitoring system
- Onshore bench testing & sea trials (Firth of Forth)
- Develop commercialisation roadmap

|FOCUS AREAS|

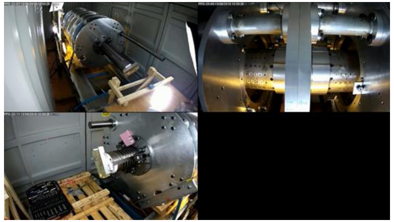
- <u>Optimisation</u>; Geometry & mass, bearing configuration, power & control system
- <u>Seagoing operability</u>; Marinisation and integration with WEC type platform
- <u>Scalability</u>; Design, manufacturing processes & materials
- <u>Modularity</u>; Improved assembly & maintenance

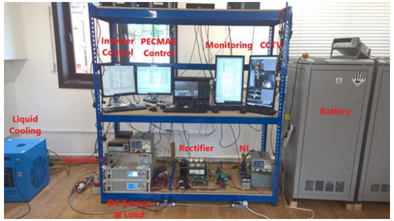
|KEY OBJECTIVES|

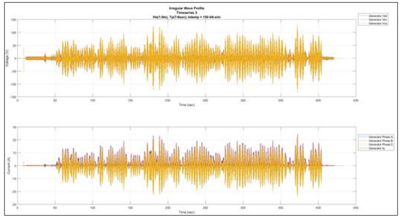
- Bring PECMAG to a readiness level for deployment on pre-commercial demonstrator
- Deliver intermediate unit size with the ability to support WEC testing at EMEC
- Meet efficiency targets that satisfy requirements of commercialisation



Timeline







- Project Kick Off
- System Spec & Requirements Definition
- Extended Testing Stage 2 Hardware
- Design & Optimisation
- Manufacturing Phase
- Performance Bench Testing
- Offshore Testing
- Techno-economic analysis
- Final Report

Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1

2018 **2019** **2020**


OCEANEERING®
Connecting What’s Needed With What’s Next™
OCEANEERING

wave energy SCOTLAND

HIE
Highlands and Islands Enterprise
Iomairt na Gàidhealtachd 's nan Eilean

The Scottish Government
Riaghaltas na h-Alba

UMBRAGROUP

EMERGE

Electro-MEchanical Reciprocating GEnerator

emerge (/ɪˈmɜːdʒ/): to appear, or to become recognized

Luca Castellini
Energy R&D and BD Manager

umbragroup.com

Electro-MEchanical Reciprocating GEnerator - UMB PTO32

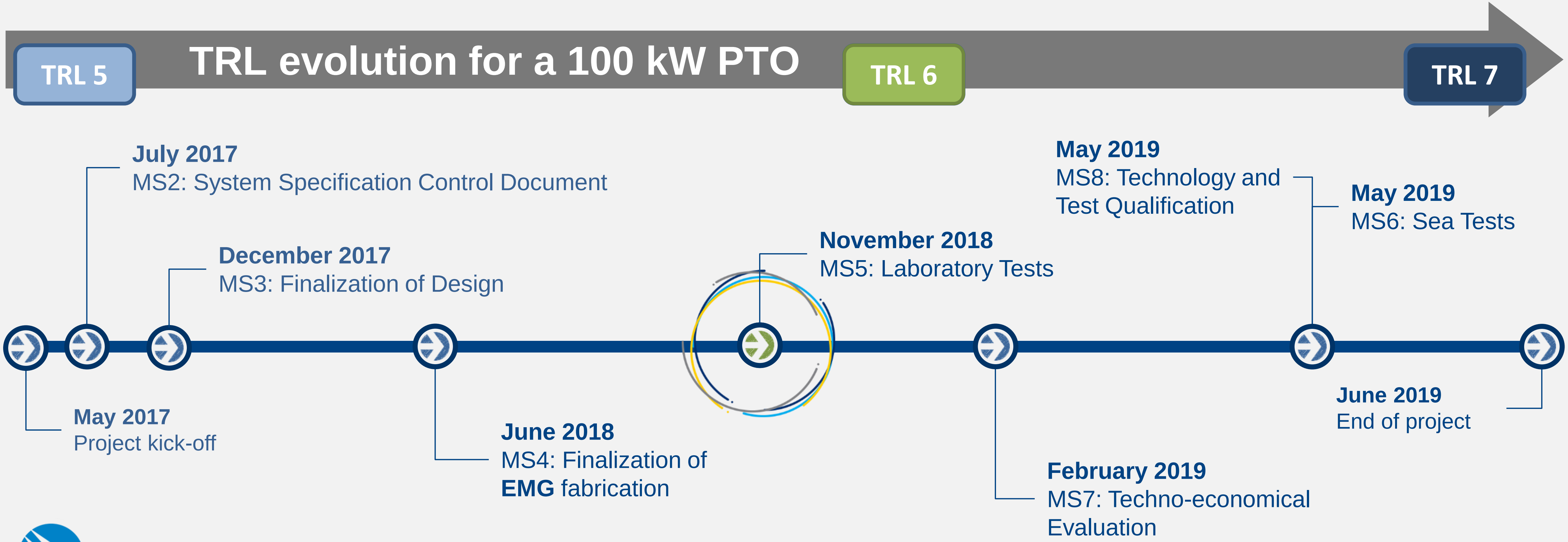
Content of this presentation

- *Introduction*
- *UMBRAGROUP innovation*
- *EMERGE project update*
- *Conclusions*

EMERGE - WES PTO STAGE 3 PROJECT

Introduction

wave energy SCOTLAND



UMBRAGROUP innovation

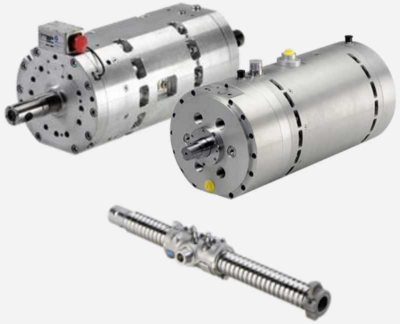
wave energy SCOTLAND

1972

FAG and GEPI found UMBRA to produce high-precison bearings

1978

The company starts producing ballscrews for aviation industries



2018

Production of bearings, ballscrews, actuators and **generators** for a wide range of industries

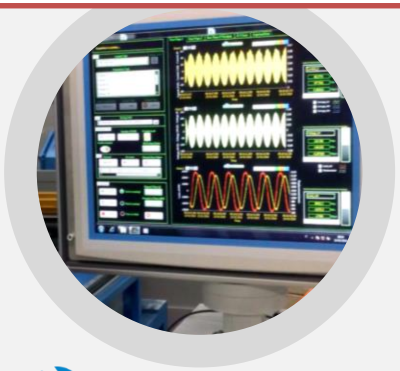
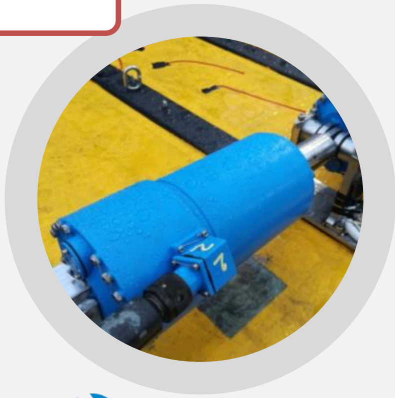
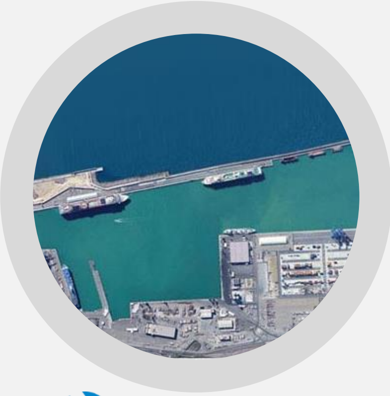
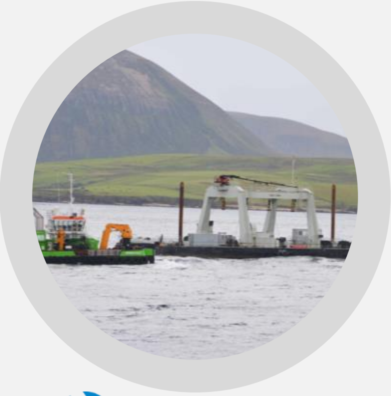
Technology transfer from other sectors to OCEAN REN. ENERGY

EMERGE - WES PTO STAGE 3 PROJECT

UMBRAGROUP innovation

wave energy SCOTLAND

ANALYSIS & SIMULATIONS

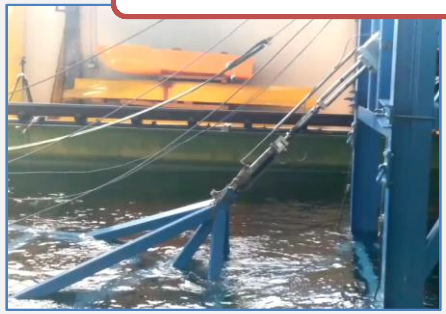
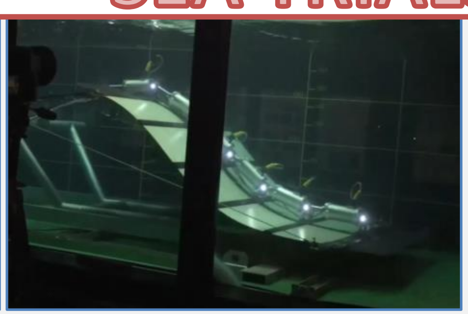
2015 | 2016 | 2017 | 2018 | 2019

DRY TESTS

TANK TESTS

SEA TRIALS

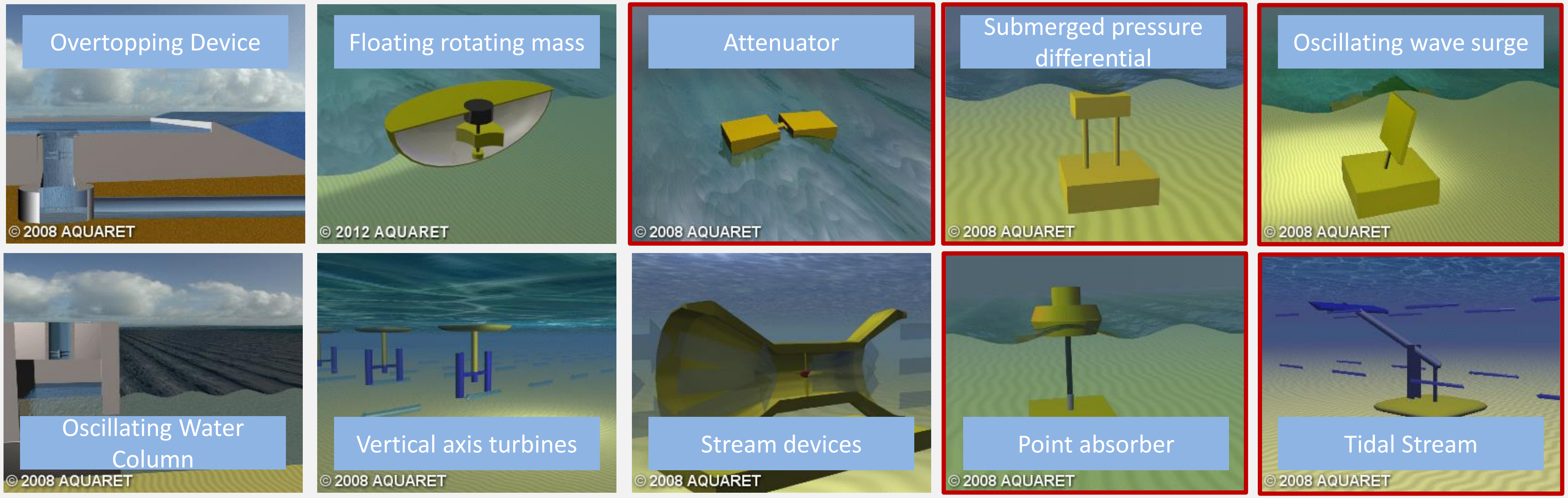



EMERGE - WES PTO STAGE 3 PROJECT

UMBRAGROUP innovation

EMG best integration



Wave energy conversion concepts that could directly integrate at least one product from UMBRAGROUP (bearings, ballscrews, actuators, rotary or linear generators)

EMERGE - WES PTO STAGE 3 PROJECT

EMERGE project

wave energy SCOTLAND

June 2018
MS4: Finalization of **EMG** fabrication

November 2018
MS5: Laboratory Tests

May 2019
MS6: Sea Tests

February 2019
MS7: Techno-economical Evaluation

June 2019
End of project

Functional tests

Performance tests

Sealing tests

HwiL tests

TRL 5

TRL evolution for a 100 kW PTO

TRL 6

TRL 7

MS4: Finalization of **EMG** fabrication (end of June 2018)

EMERGE - WES PTO STAGE 3 PROJECT

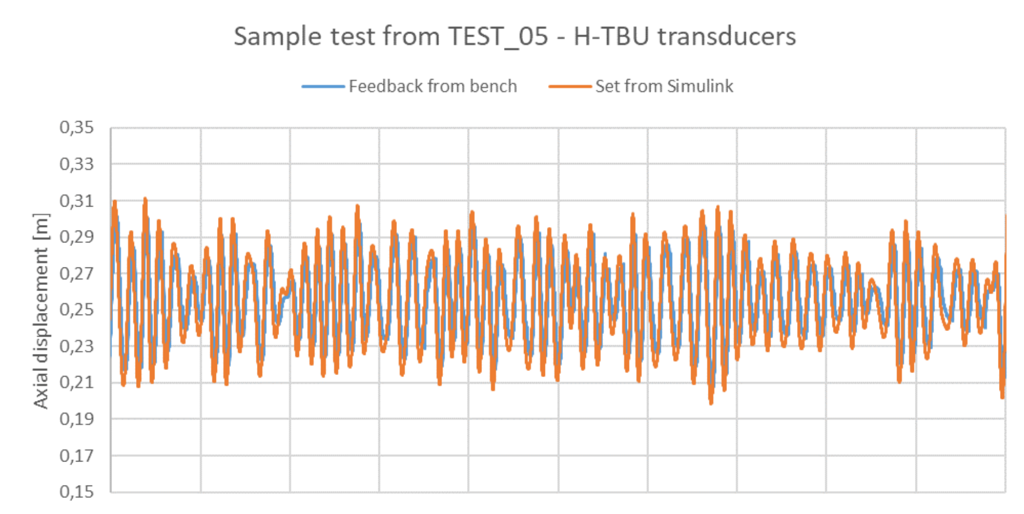
EMERGE project

Overview of the test area

EMERGE - WES PTO STAGE 3 PROJECT

EMERGE project

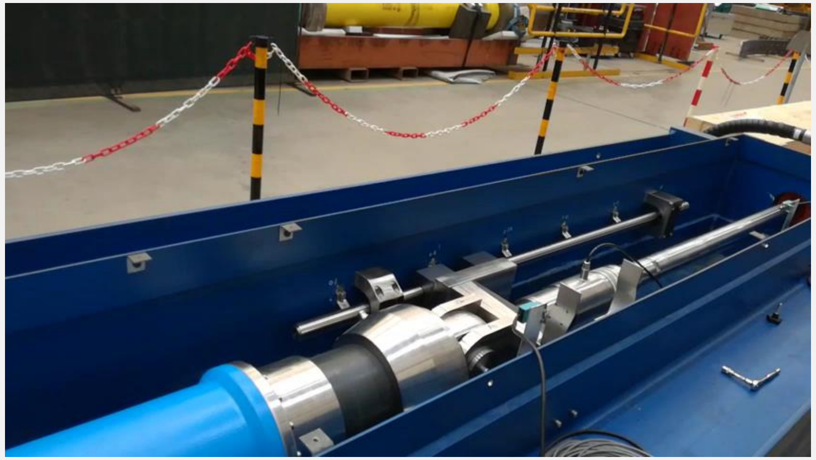
HWiL test with synthetic sea state profiles

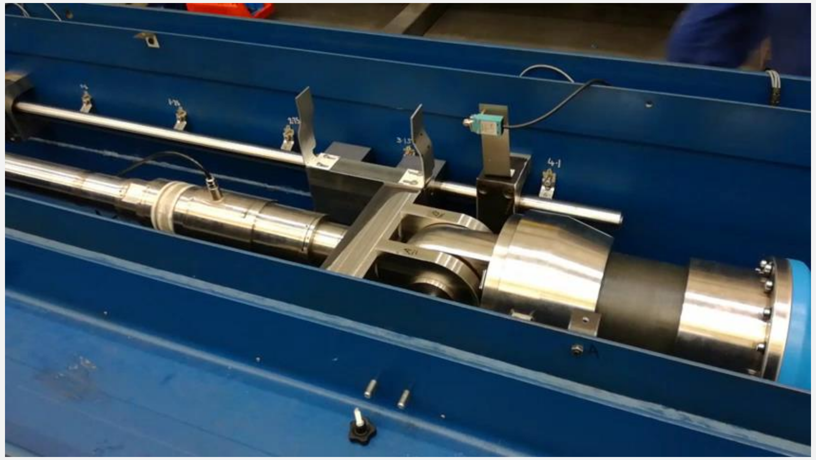


EMERGE - WES PTO STAGE 3 PROJECT

EMERGE project

wave energy SCOTLAND





EMERGE - WES PTO STAGE 3 PROJECT

EMERGE project

wave energy SCOTLAND

ENDORSEMENT and TECHNOLOGY FEASIBILITY STATEMENT by BUREAU VERITAS

BUREAU VERITAS 1828

BUREAU VERITAS

BUREAU VERITAS MARINE & OFFSHORE SAS

STATEMENT OF FEASIBILITY

100 KW ELECTRO-MECHANICAL RECIPROCATING GENERATOR

Statement Ref.:	AT17066 / RRM.18.00012 Rev.0
Technology Owner:	Umbra Cuscinetti S.p.a
Name of Technology:	Electro-MEchanical Reciprocating Generator (EMERGE)
Technology description:	Electro-Mechanical Generator.
Technology application:	The EMERGE project involves an Electro-Mechanical Generator (EMG), which will be integrated with a Point-Pivoted Buoy (PPB) and a Power, Control and Monitoring (PCM) system to form Wave Energy Converter (WEC).

This is to state that the above technology has been assessed in accordance with qualification procedures and requirements of the guidance Bureau Veritas NI 525 DTM R00 E– Risk Based Qualification of New Technology Methodological Guidelines [1] and Technology Readiness Assessment of Horizon H2020 Work programme 2016-2017 – Annex G.

The technology specification requirements have been defined by the technology owner with regards to component performance requirements, Technology Readiness Level (TRL) requirements, and applicable standards for design and material treatment and raw materials procurement.

BV has been involved in the Technology Assessment, divided in 3 steps:

- Technology Composition Analysis, which describes the functions of the technology components;
- Technology Categorization, which indicates which component of the technology is novel and needs to be focused on during the qualification activities; and
- Qualification-Failure Modes, Effects and Criticality Analysis (Q-FMECA), which identifies threats and weaknesses of the technology, and identifies the technology qualification activities which will be required for the project in order to demonstrate the ability of the technology to meet the specification requirements in the intended environment.

Nineteen (19) qualification activities already exist, and seven (7) additional qualification activities have been identified during the Technology Assessment [2]. These additional activities will be included in the Technology Qualification Plan (TQP) issued by the Technology Owner.

BV considers the technology conceptually feasible as defined and thereby suited for further development and qualification according to Bureau Veritas NI 525 DTM R00 E.

Issued at Paris La Défense, France, on 25th of January 2018.

Diane RUF
Risk, Reliability & Maintenance Manager
Services Department
Bureau Veritas Marine & Offshore SAS

Olivier BENYESSAAD
Ocean Energy Market Leader
Offshore Sales & Marketing Department
Bureau Veritas Marine & Offshore SAS

BUREAU VERITAS MARINE & OFFSHORE SAS

ENDORSEMENT OF TECHNOLOGY QUALIFICATION PLAN

100 KW ELECTRO-MECHANICAL RECIPROCATING GENERATOR

Statement Ref.:	AT17066 / RRM.18.00013 Rev.0
Technology Owner:	Umbra Cuscinetti S.p.a
Name of Technology:	Electro-MEchanical Reciprocating Generator (EMERGE)
Technology description:	Electro-Mechanical Generator.
Technology application:	The EMERGE project involves an Electro-Mechanical Generator (EMG), which will be integrated with a Point-Pivoted Buoy (PPB) and a Power, Control and Monitoring (PCM) system to form Wave Energy Converter (WEC).

This is to endorse that the Qualification Plan [3] of the above mentioned technology is in accordance with the guidance Bureau Veritas NI 525 DTM R00 E– Risk Based Qualification of New Technology Methodological Guidelines [1] and that the technology can be proven Fit for Service through the remaining planned qualification activities identified in the Technology Qualification Plan (TQP).

Technology Qualification Plan (TQP) has been issued by the Technology Owner based on the additional qualification activities identified during the Technology Assessment [2], and more particularly the Qualification-Failure Modes, Effects and Criticality Analysis (Q-FMECA).

BV has checked the technical aspects of the TQP including the consistency of the estimated schedule.

Issued at Paris La Défense, France, on 25th of January 2018.

Diane RUF
Risk, Reliability & Maintenance Manager
Services Department
Bureau Veritas Marine & Offshore SAS

Olivier BENYESSAAD
Ocean Energy Market Leader
Offshore Sales & Marketing Department
Bureau Veritas Marine & Offshore SAS

CONCLUSIONS

wave energy SCOTLAND

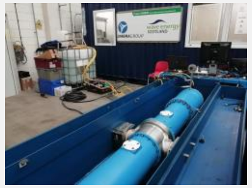
- Technology transfer from other sectors to OCEAN REN. ENERGY
- Highly reliable and efficient solution (proved by robust methodology)
- Third-party technology validation
- High TRL and established manufacturing capabilities
- Clear ROADMAP to commercialization












UMBRAGROUP

THANK YOU FOR THE ATTENTION

Wave Energy Scotland Third Annual Conference: #wesanconf18

Project Neptune Update: Component Manufacture, Machine Assembly & Testing Overview

Joseph Burchell

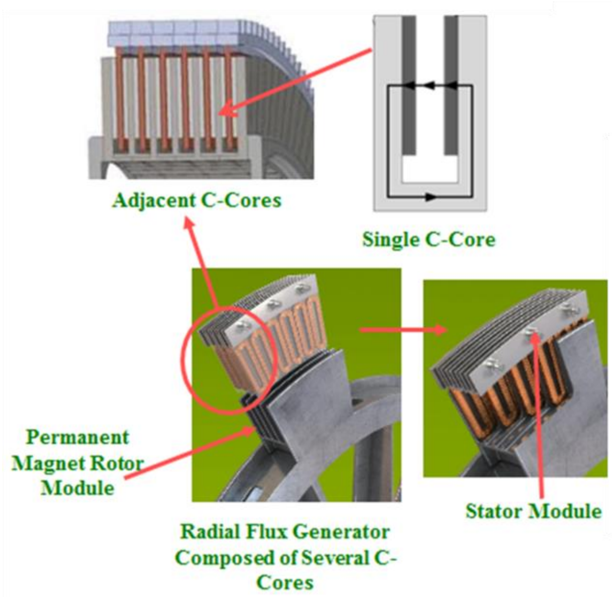
University of Edinburgh, School of Engineering

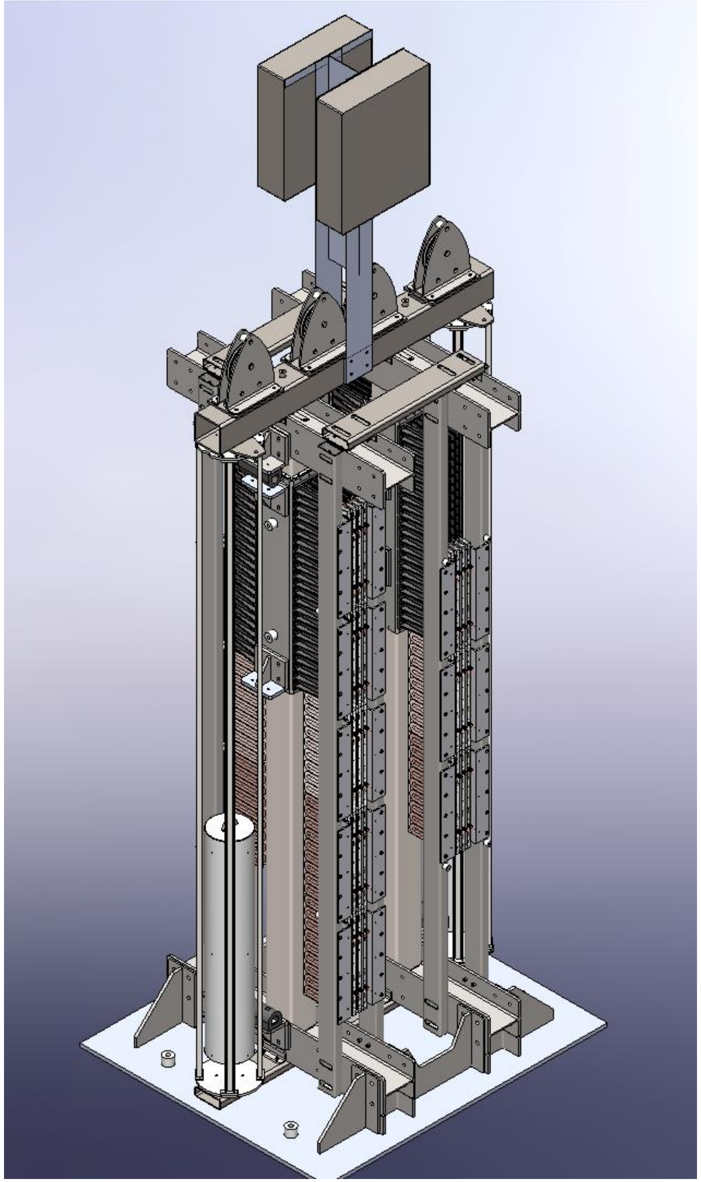
Institute for Energy Systems

Project Neptune Status

- Project Neptune
- Coil Blade and Module Manufacturing
- Translator and Magnet Module Manufacturing
- Test Rig Manufacture
- Testing at Quartz Elec and Leith docks

Project Neptune





- No magnetic attraction forces closing the airgap,
- No cogging torque, and
- Air cored coils that allow for a high level of modularity leading to multi stage machines for higher energy availability and a reduction of O&M costs.

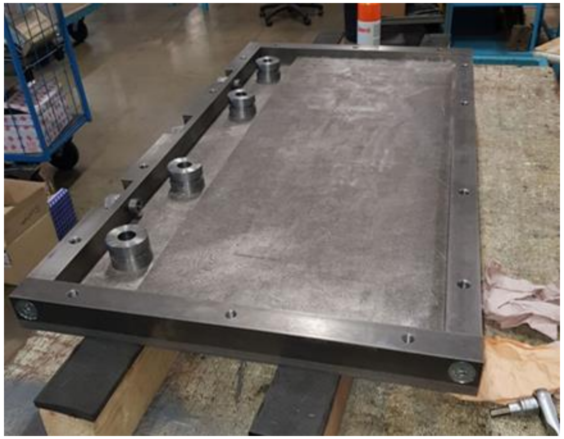
Coil Blade and Module Manufacture

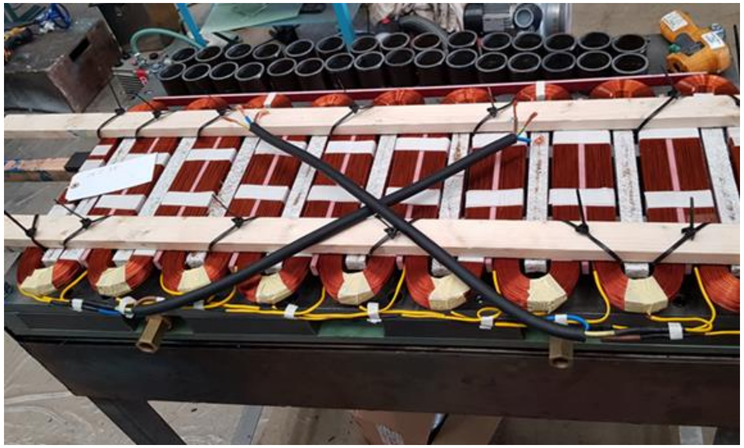
THE UNIVERSITY of EDINBURGH
School of Engineering

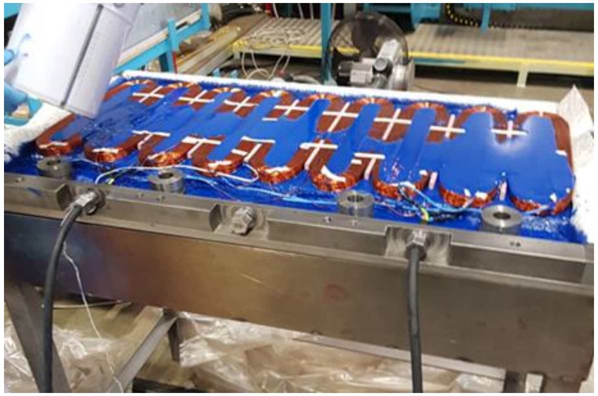
Institute for Energy Systems

150
Celebrating engineering innovation from 1868 – 2018… and onwards

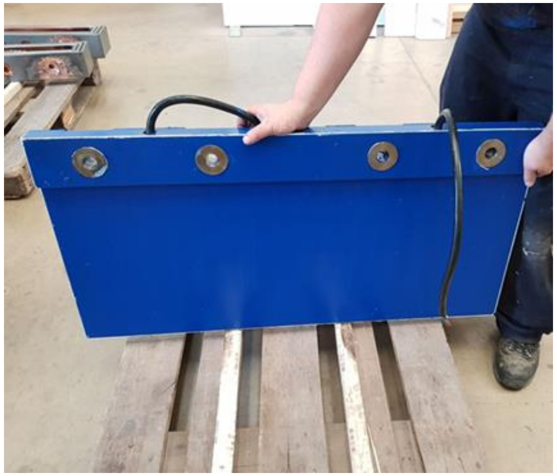
Coil Blade and Module Manufacture



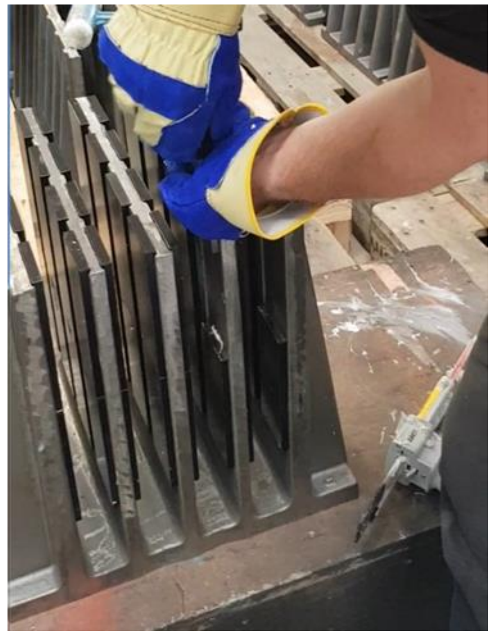


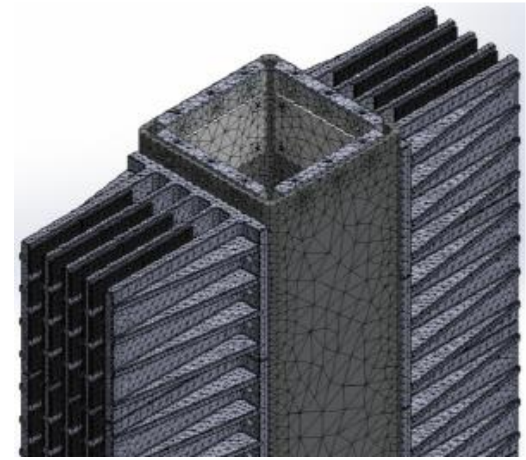


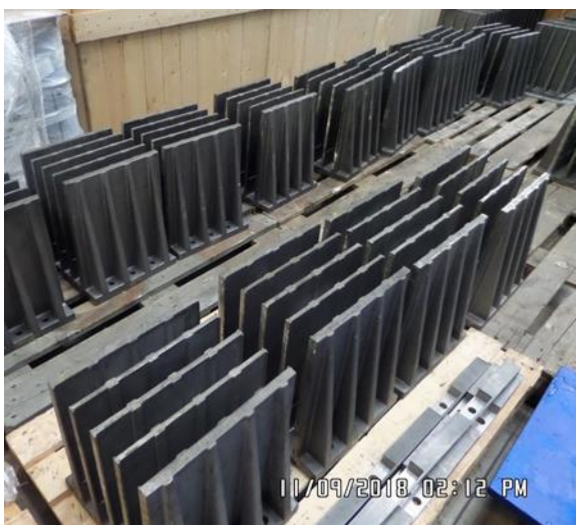
Coil Blade and Module Manufacture



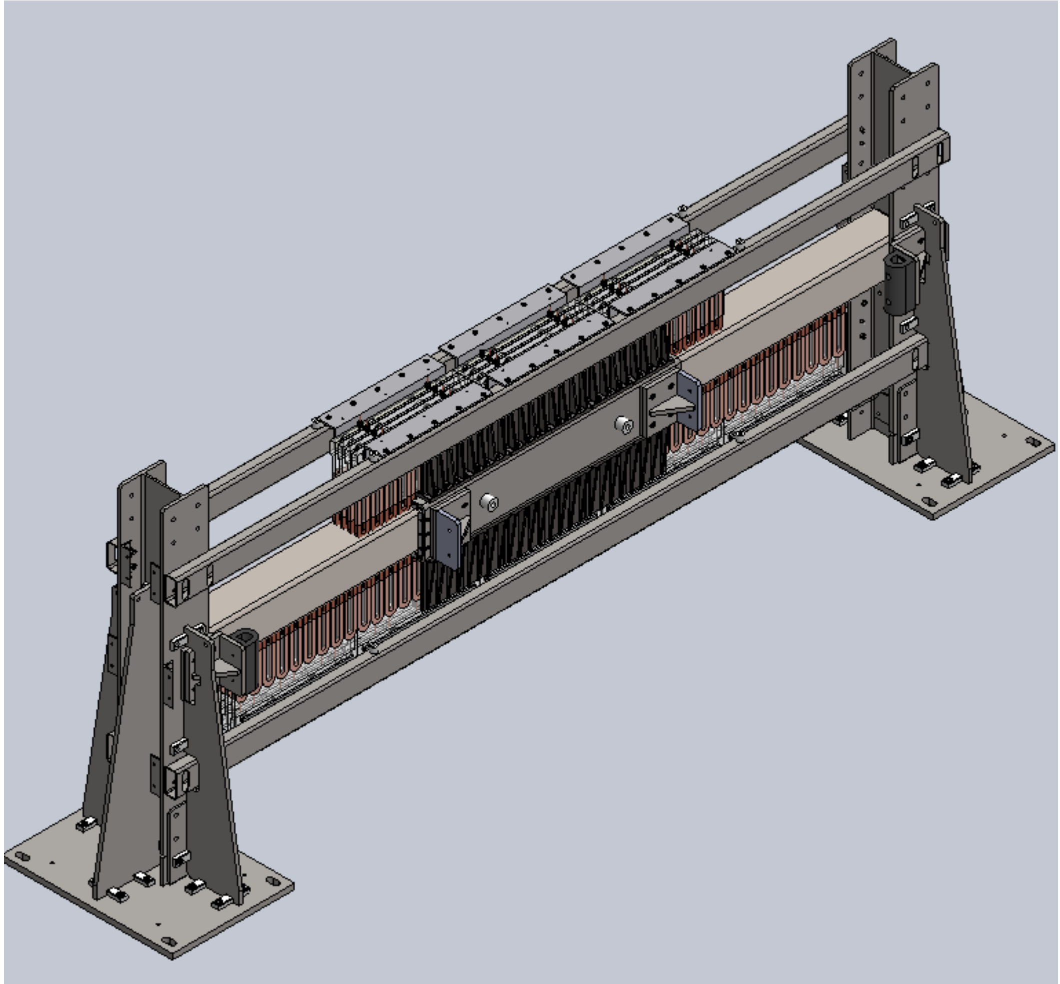
Translator and Magnet Module Manufacturing

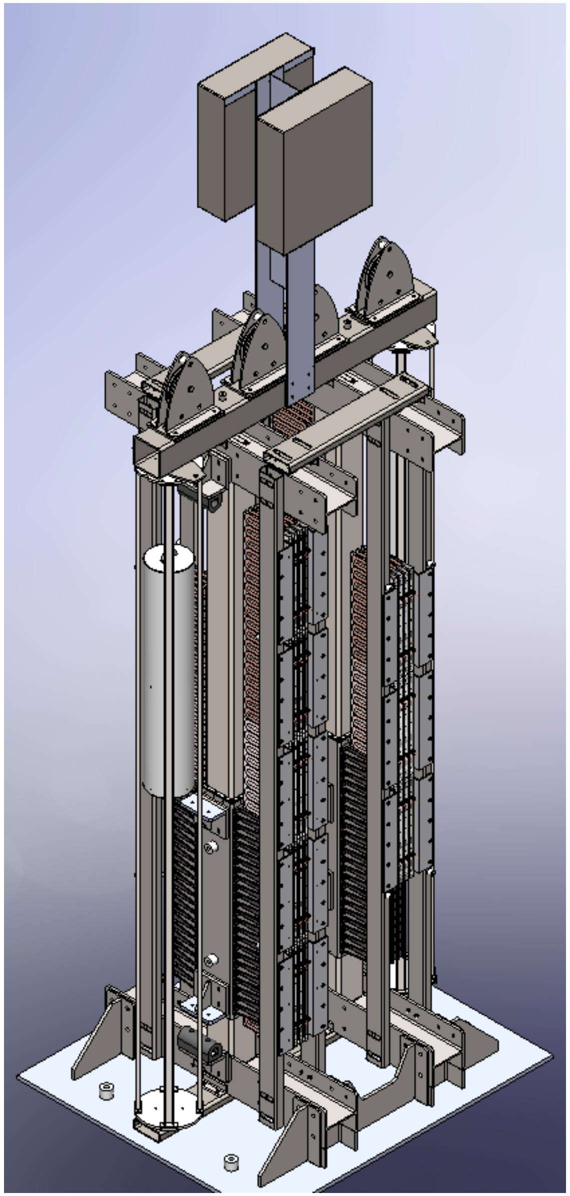






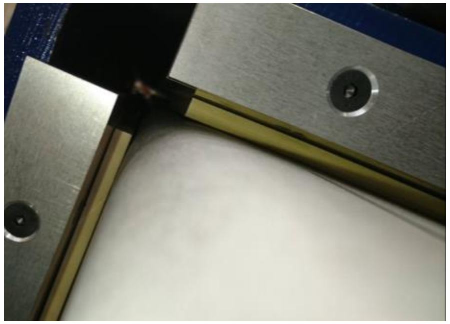
Test Rig Manufacture



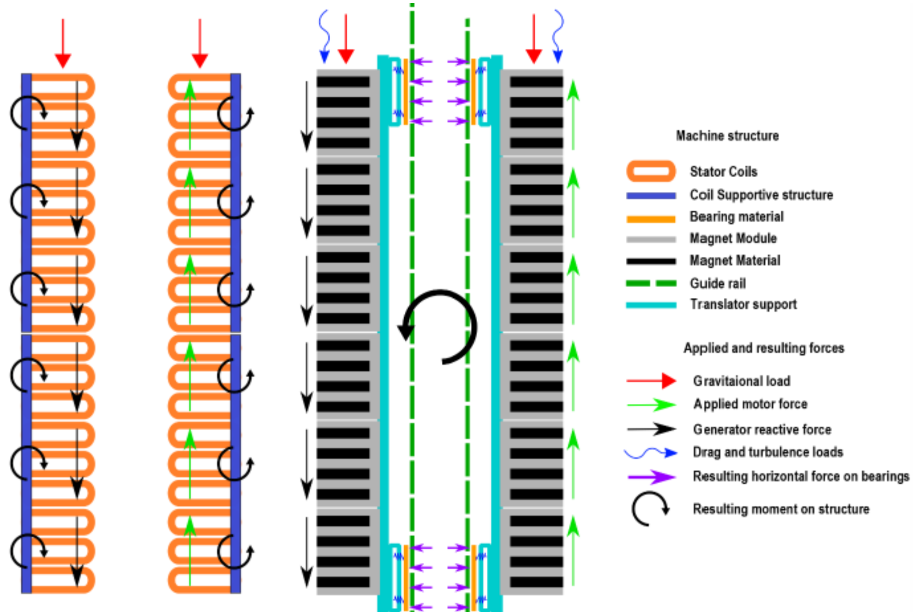


Test Rig Manufacture

Test Rig Manufacture

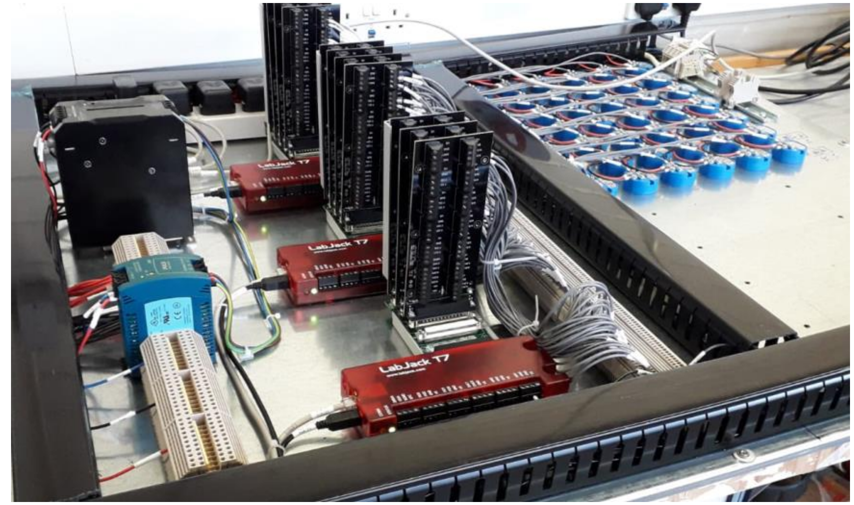


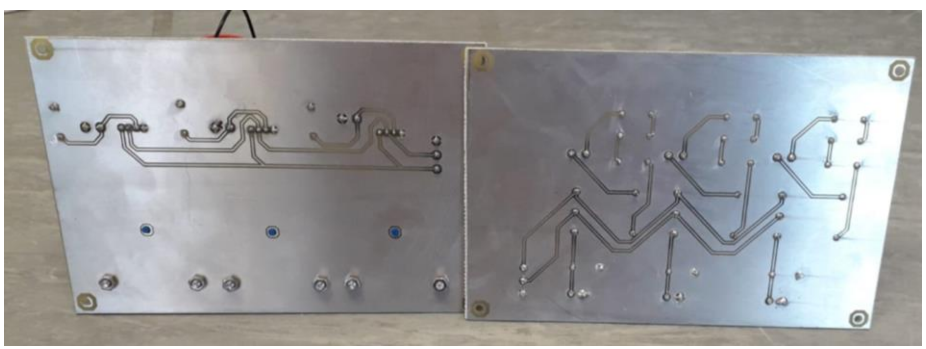
Testing at Quartz Elec and Leith docks

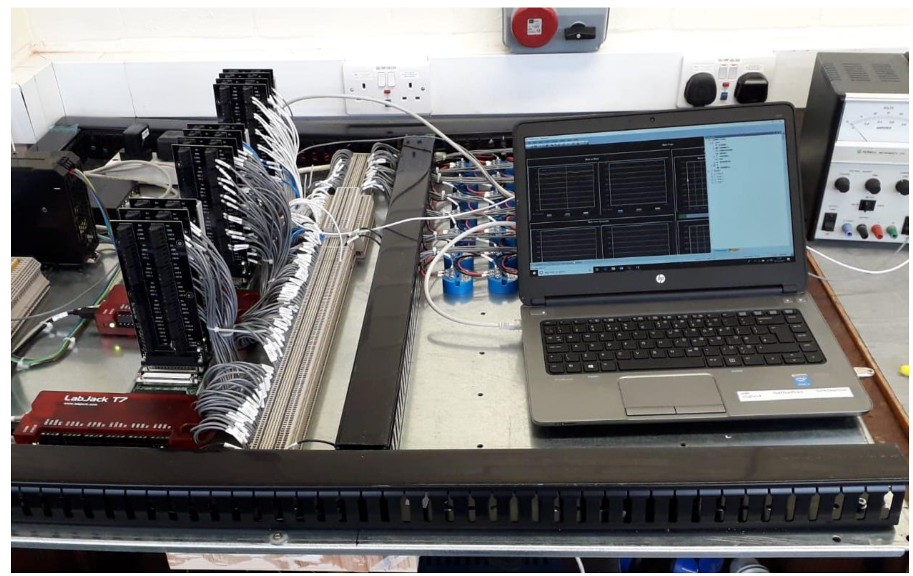


Coils and supporting structure

Traslator and support structure







Testing at Quartz Elec and Leith docks