Institution of MECHANICAL ENGINEERS

North Western Region

Ocean Energy & Talos Wave Energy Converter

by Professor George Aggidis

18:00-19:30 GMT

25 November 2022

Lancaster University

Improving the world through engineering

Engineering | Lancaster University

YOUR SPEAKER

Professor George Aggidis

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Institution of MECHANICAL ENGINEERS

Lancaster University

Ocean Energy and TALOS Wave Energy Converter

IMechE Fluid Machinery Group

EUR ING Professor

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25 November 2022

Overview

- Wave Energy Generation Systems
- Tidal Power Generation Systems
- TALOS Wave Energy Converter
- Conclusions

ENERGY - LUREG Research

Lancaster University

Research on Renewable Energy & Fluid Machinery

- Generic & Applied

Energy & Renewables

- Computational & Experimental Modelling
- Device Development & Power take off
- Computational Fluid Dynamics & Control
- Economics, Resource & Condition Monitoring

Novel Topology Fluid Machinery & Turbines

- Computational Fluid Dynamics, Turbine Design & Analysis
- Direct Drive & In Line Turbines
- Siphonic Low Head & Low Cost Turbine Research
- Fluid Machinery reliability & Energy Efficiency

Funded by EPSRC, Carbon Trust, EU, RDAs, Utilities and Industry

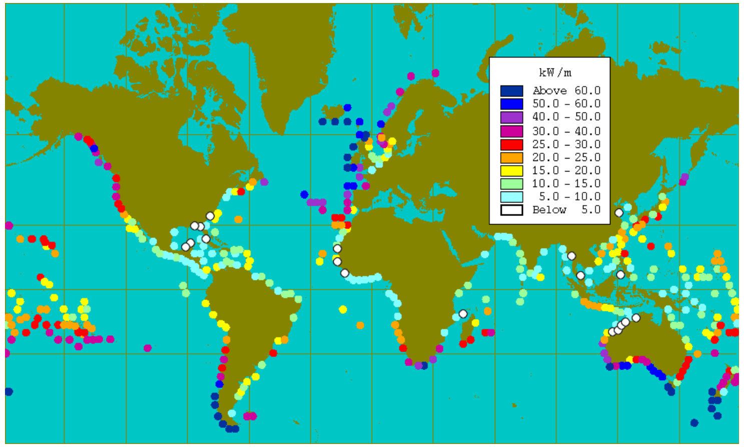
Lancaster University Engineering Building

UK & Worldwide Wave Energy Resource

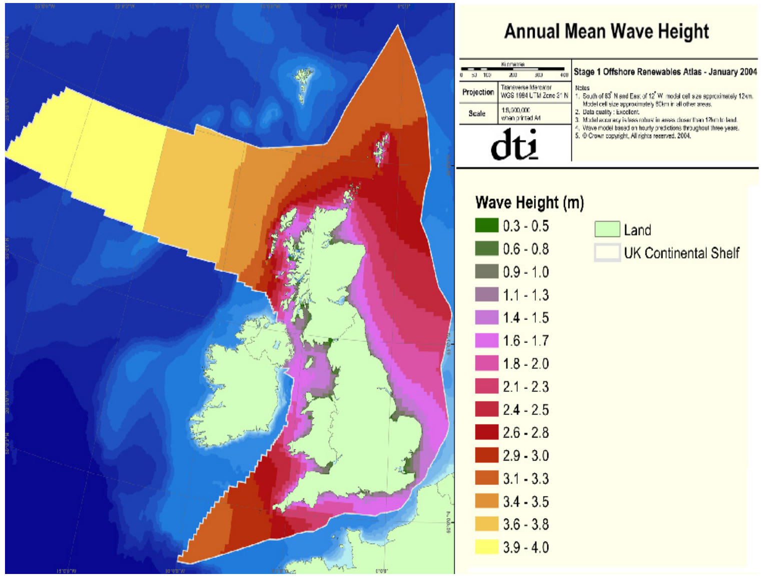
- Worldwide practical resource estimated 2000-4000 TWh/year

- UK practical resource estimates:
  - Offshore 50 TWh/year
  - Near-shore 7.8 TWh/year
  - Shoreline 0.2 TWh/year

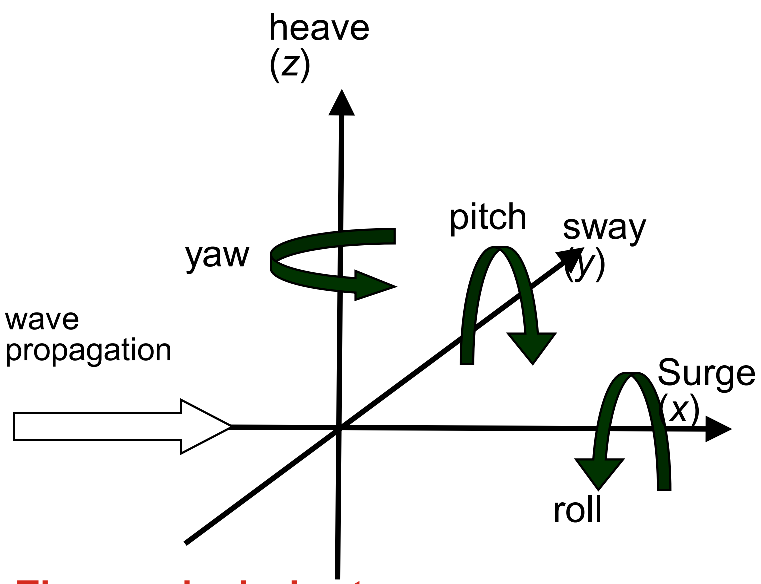
- Power at specific site:
  - Power per metre crest length
  - Annual Mean Wave Height



Annual average wave energy flux per unit width of wave crest (kilowatts per m)



Wave Energy Converter Systems (WECs)

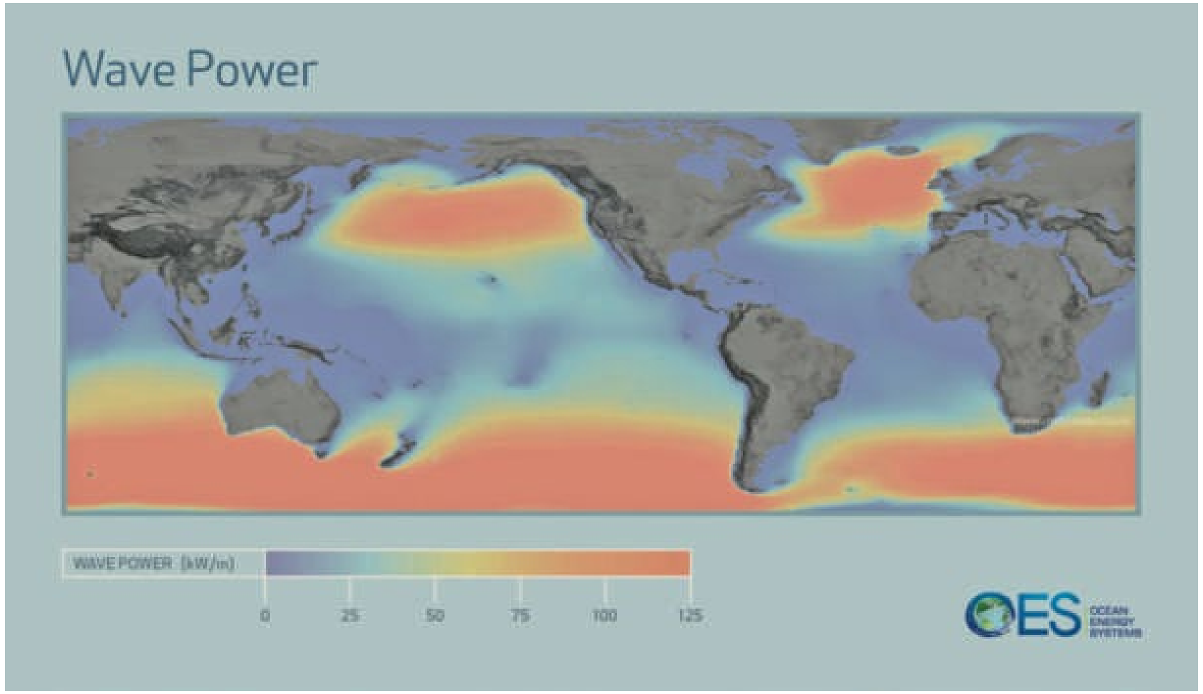


- **Three main device types:**
  - Shoreline
  - Near-Shore
  - Offshore
- **Methods of power extraction**
  - Heave
  - Pitch
  - Surge
  - Overtopping
  - Oscillating Water Column (OWC)

U.S. DEPARTMENT OF ENERGY

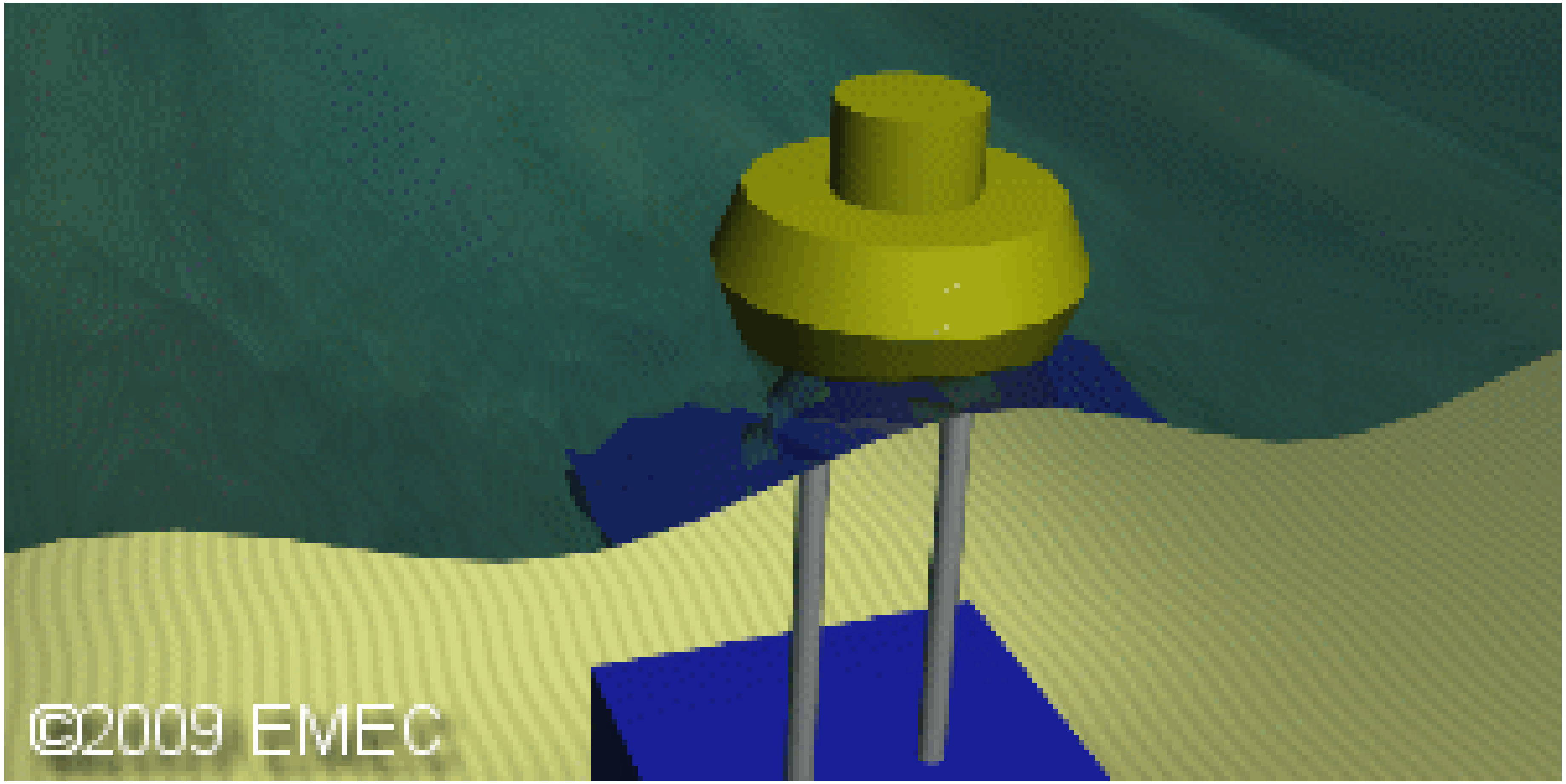
EMEC ORKNEY

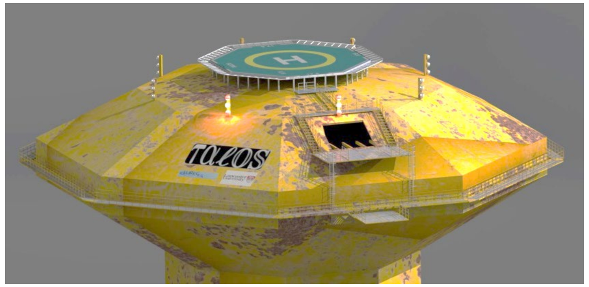
A GLOBAL CENTRE OF EXCELLENCE IN MARINE ENERGY TESTING AND RESEARCH



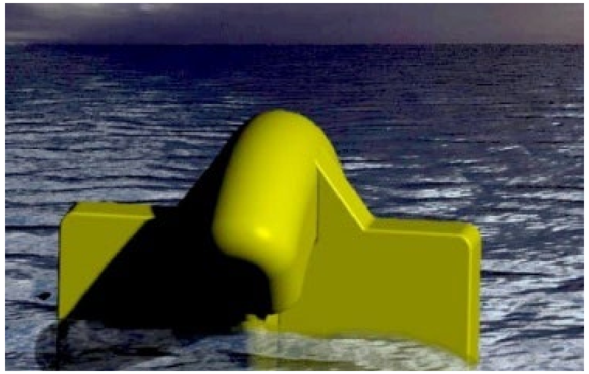
Global annual mean wave power distribution. Source: IEA-OES, 2014

Point absorber



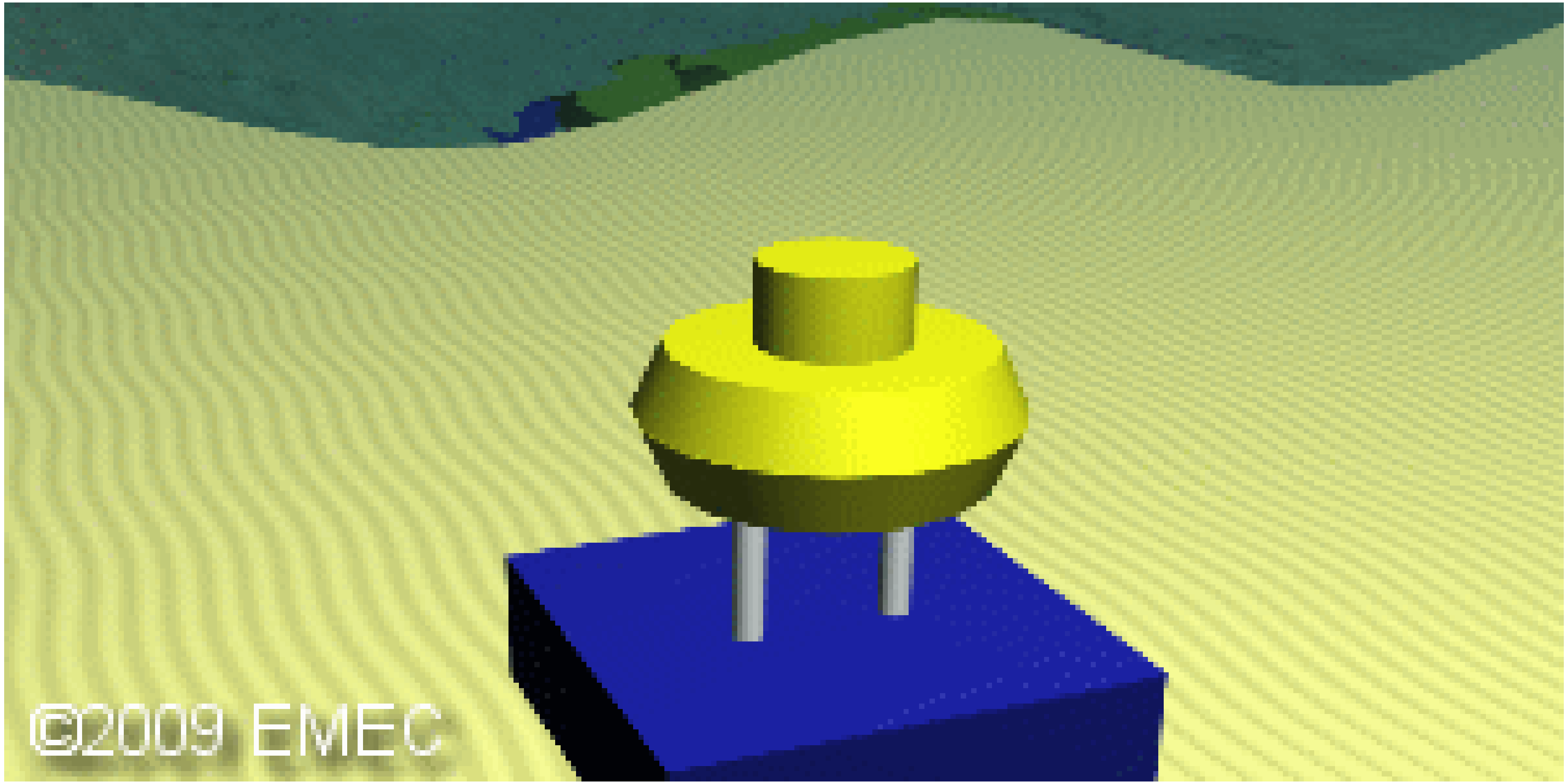


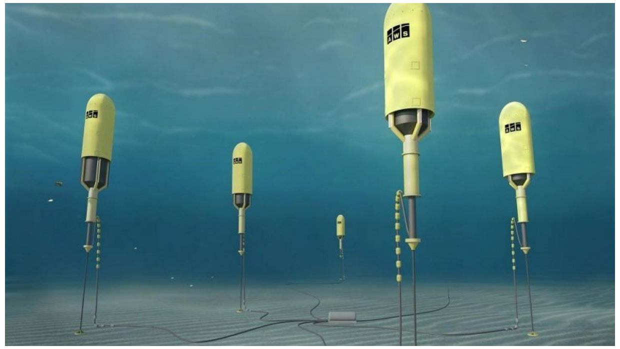
Aggidis, G.A. and Taylor, C.J., 2017. Overview of wave energy converter devices and the development of a new multi-axis laboratory prototype. *IFAC-PapersOnLine*, *50*(1), pp.15651-15656.



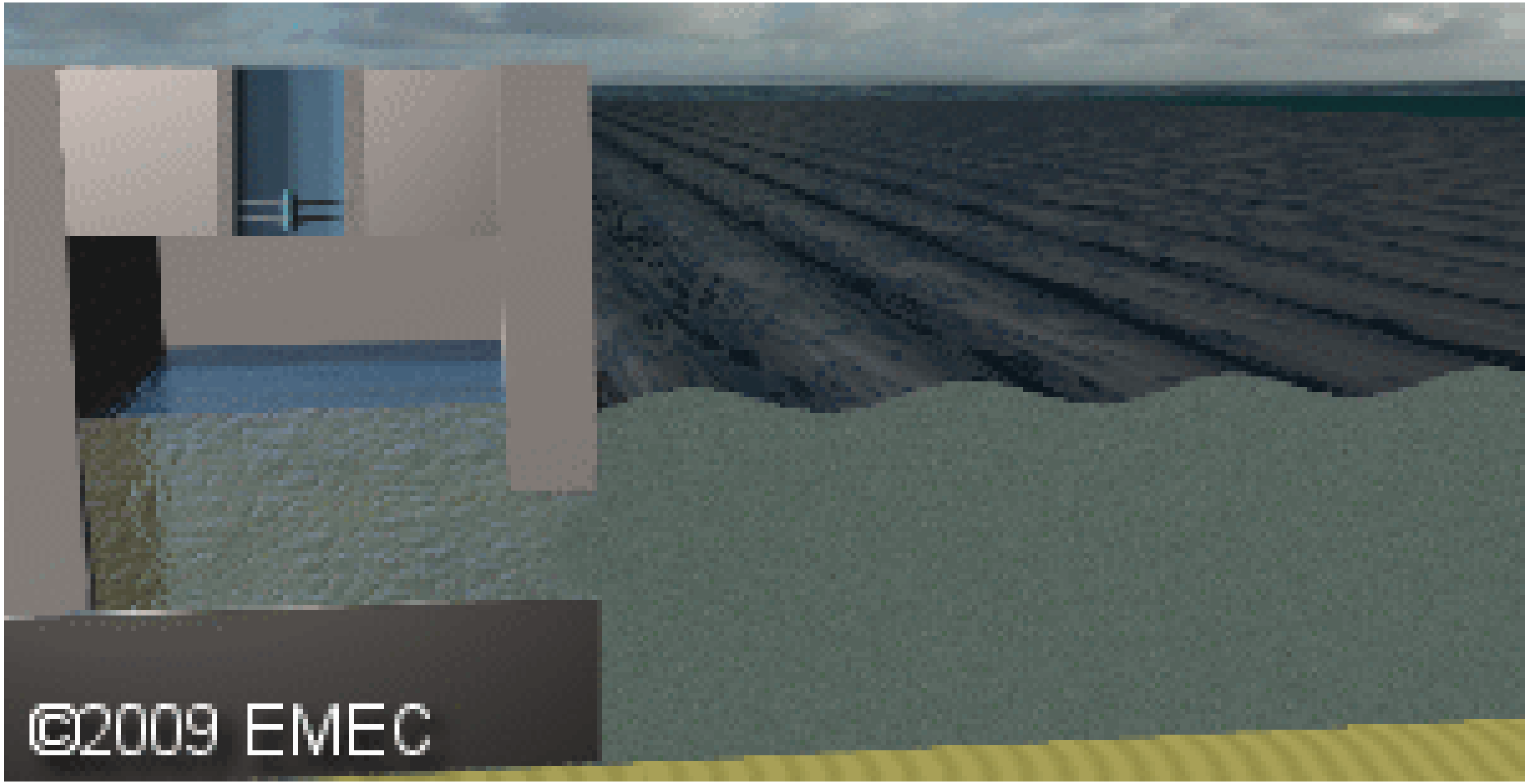
McCabe, A.P., Bradshaw, A., Meadowcroft, J.A.C. and Aggidis, G., 2006. Developments in the design of the PS Frog Mk 5 wave energy converter. *Renewable Energy*, *31*(2), pp.141-151.
Carbon Trust, Future Marine Energy (**2006**) **CT601**.
Widden, M.B., French, M.J. and Aggidis, G.A., 2008. Analysis of a pitching-and-surging wave-energy converter that reacts against an internal mass, when operating in regular sinusoidal waves. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *222*(3), pp.153-161.

Submerged pressure differential





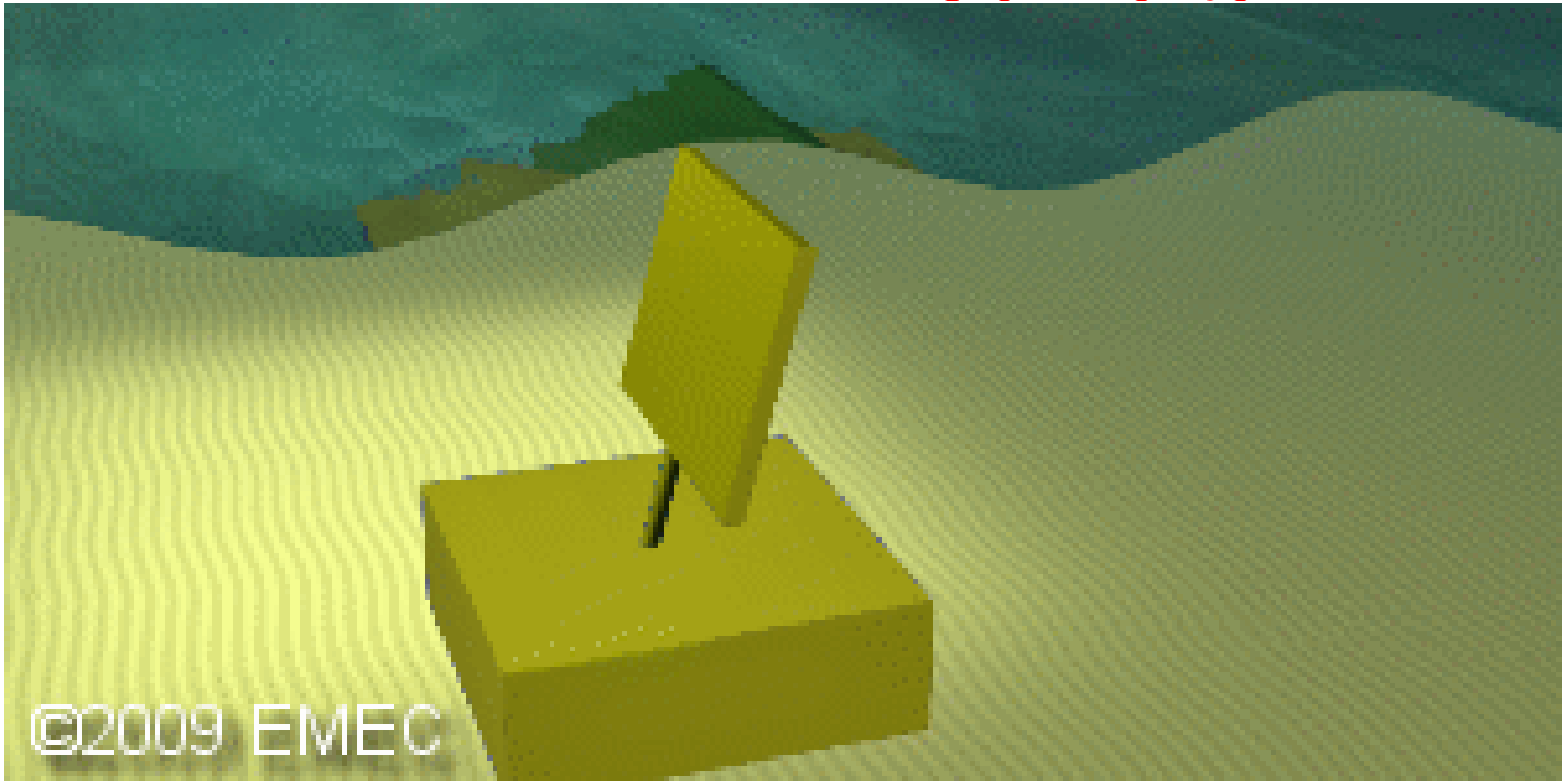
Oscillating water column

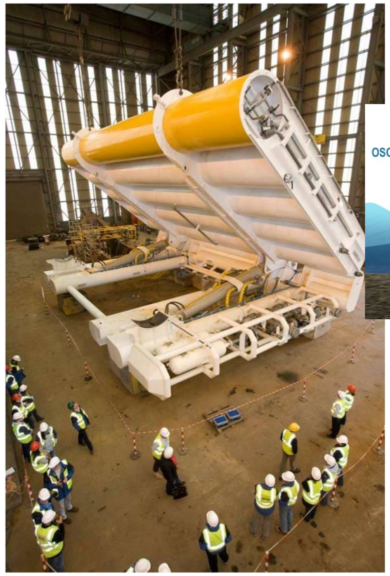


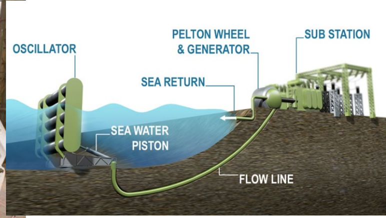
Doyle, S. and Aggidis, G.A., 2019. Development of multi-oscillating water columns as wave energy converters. *Renewable and Sustainable Energy Reviews*, *107*, pp.75-86.

Lancaster University Research on W2W Multi Oscillating Water Column Wave Energy Converter and Floating Breakwater.

Oscillating Wave Surge Converter

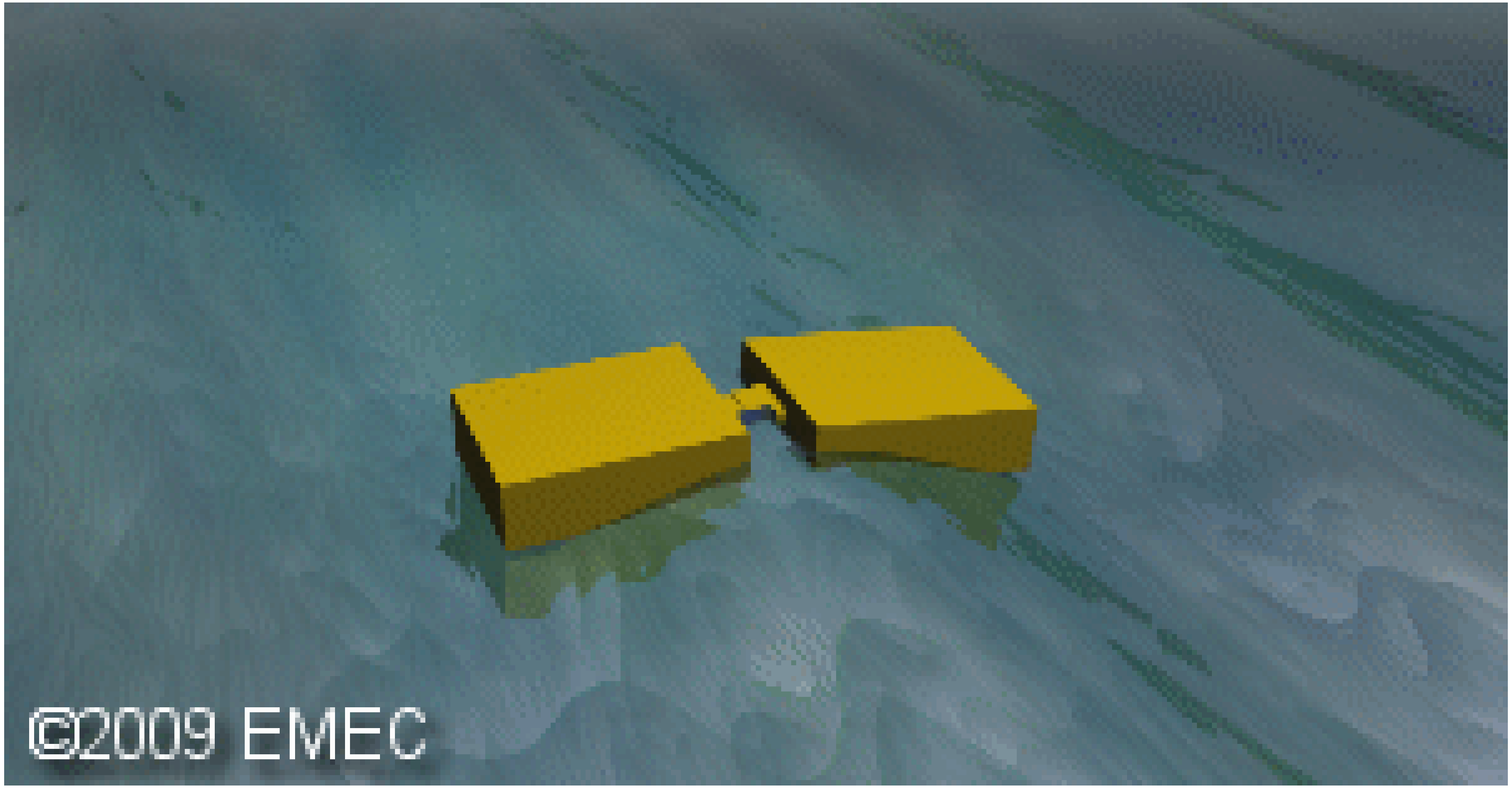




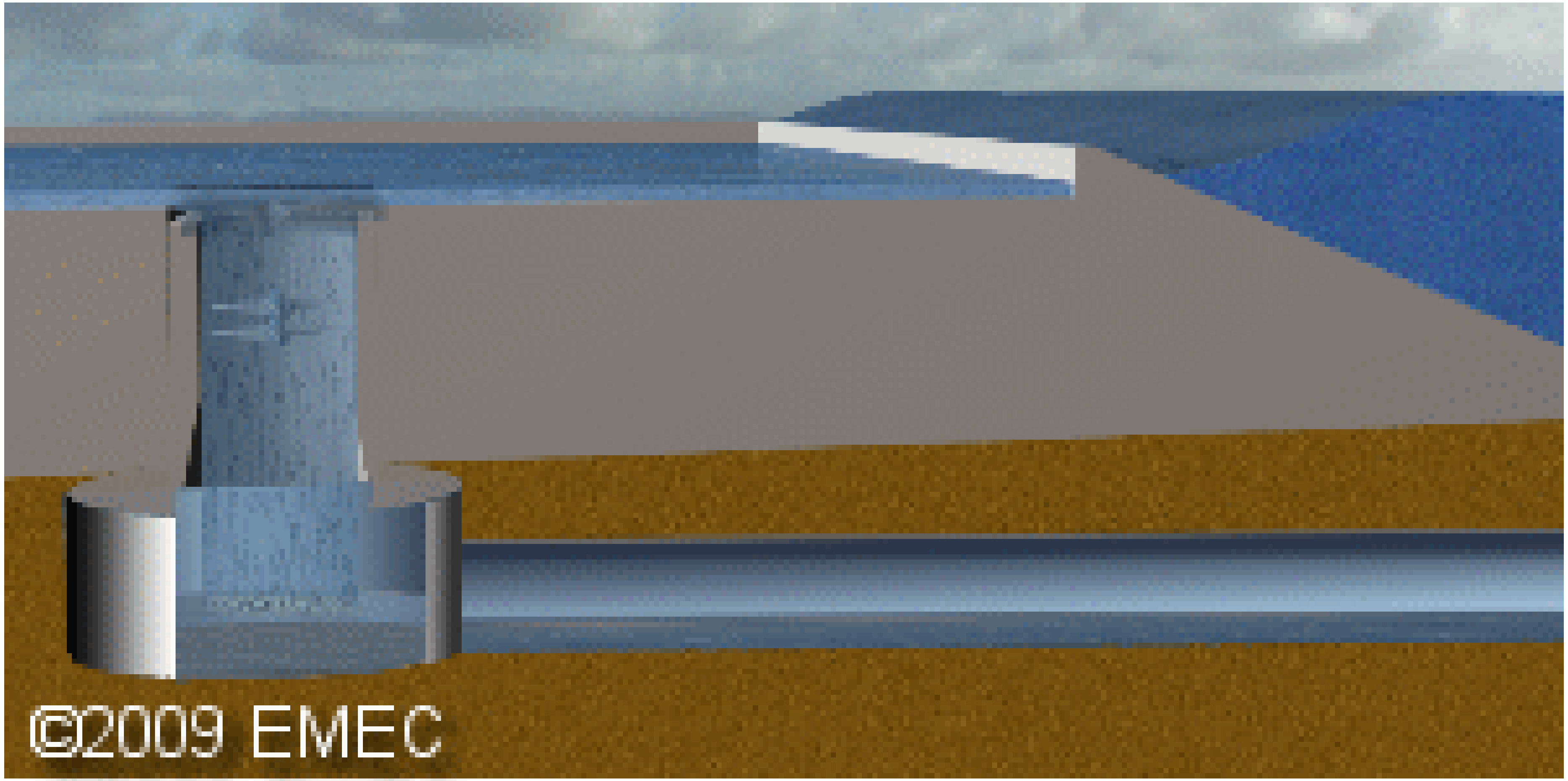


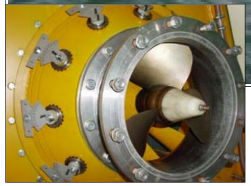
Bhinder, M.A., Mingham, C.G., Causon, D.M., Rahmati, M.T., Aggidis, G.A. and Chaplin, R.V., 2009, January. A joint numerical and experimental study of a surging point absorbing wave energy converter (WRASPA). In International Conference on Offshore Mechanics and Arctic Engineering (Vol. 43444, pp. 869-875).
Bhinder, M., Mingham, C., Causon, D., Rahmati, M., Aggidis, G. and Chaplin, R., 2009, September. Numerical and experimental study of a surging point absorber wave energy converter. In Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden (pp. 7-10).
Chaplin, R.V. and Aggidis, G.A., 2007, May. An investigation into power from pitch-surge point-absorber wave energy converters. In 2007 International conference on clean electrical power (pp. 520-525). IEEE.
Aggidis, G.A., Rahmati, M.T., Chaplin, R.V., McCabe, A.P., Bhinder, M.A., Mingham, C.G. and Causon, D.M., 2009, January. Optimum power capture of a new wave energy converter in irregular waves. In International Conference on Offshore Mechanics and Arctic Engineering (Vol. 43444, pp. 885-890).

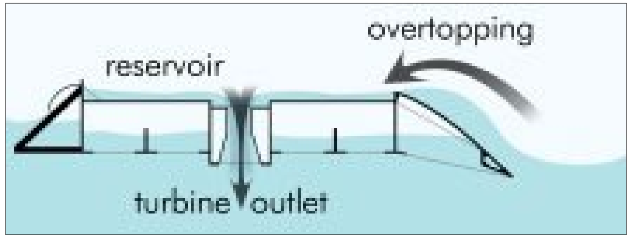
Attenuator



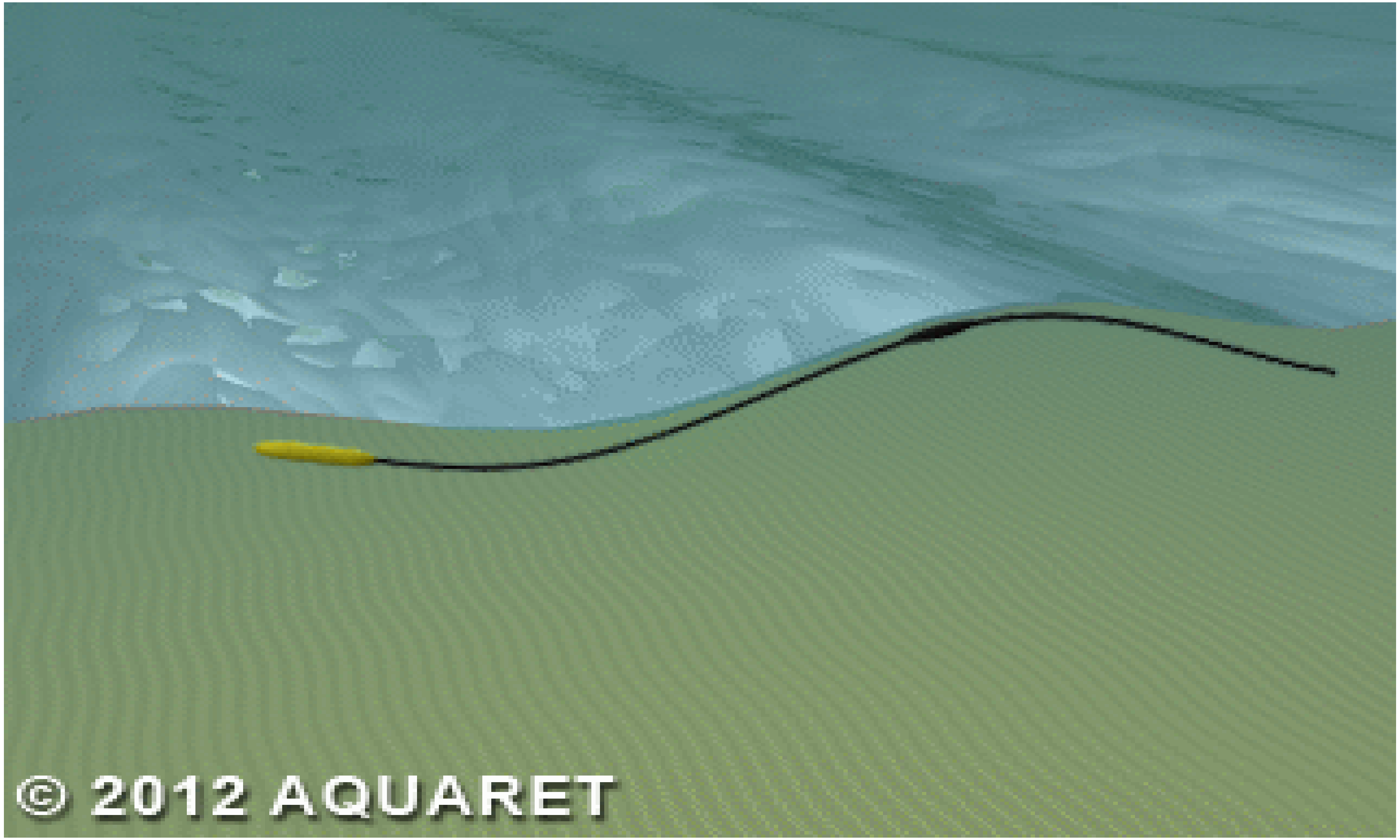
Overtopping device

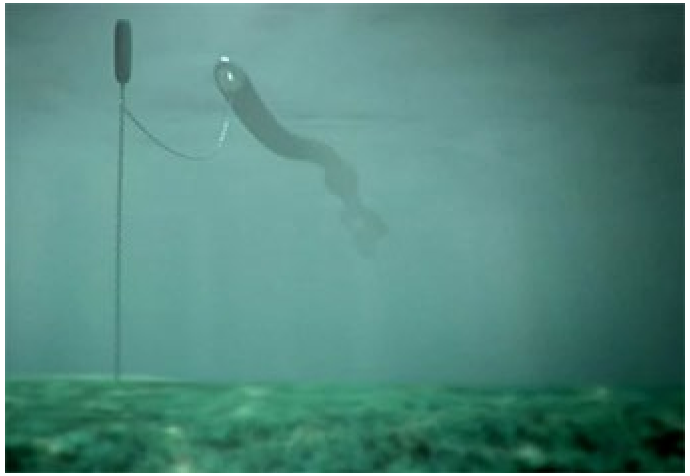




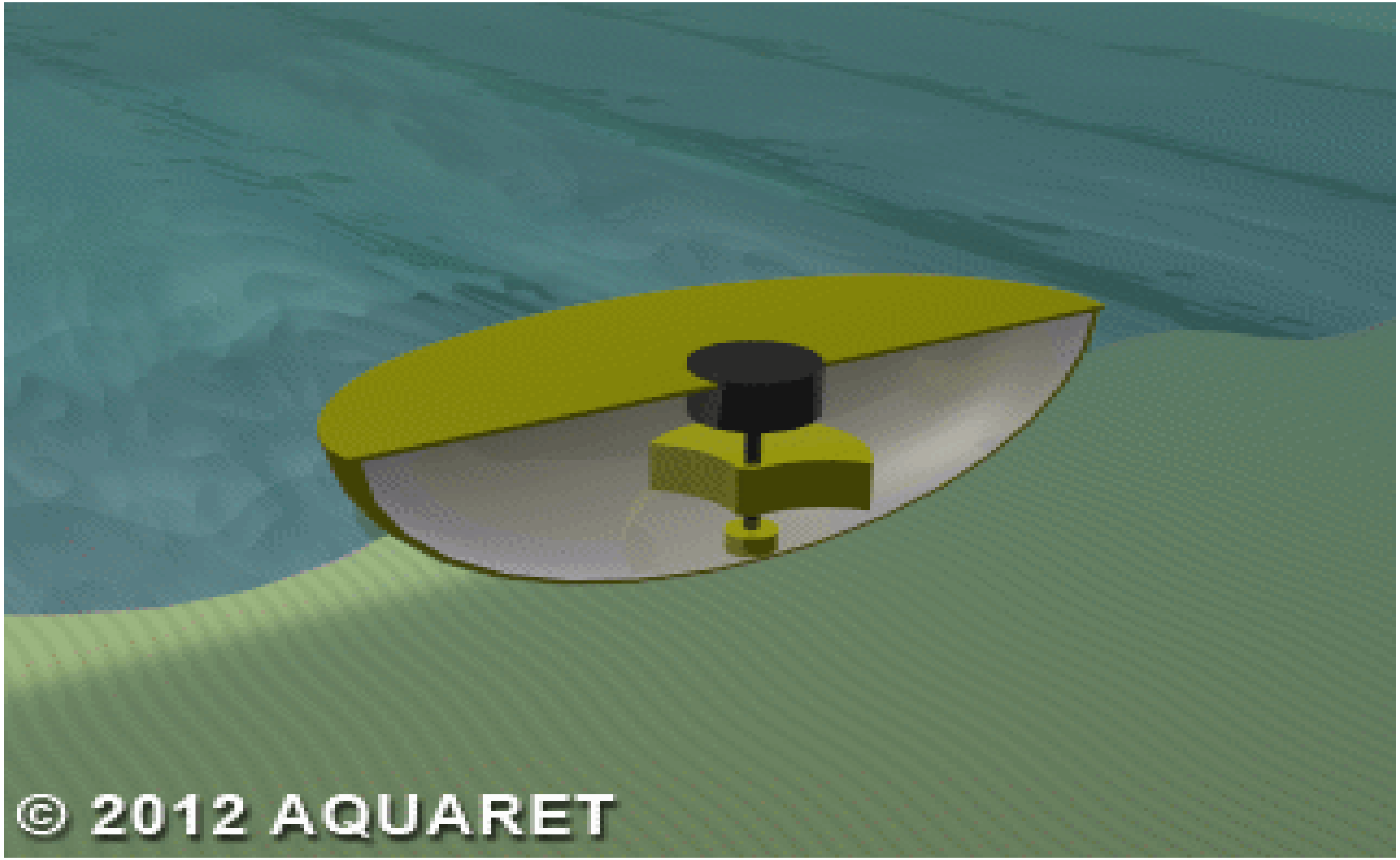


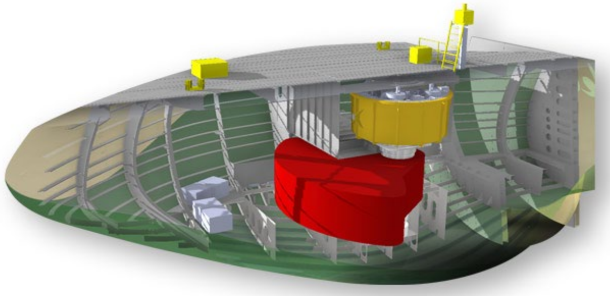
Bulge wave





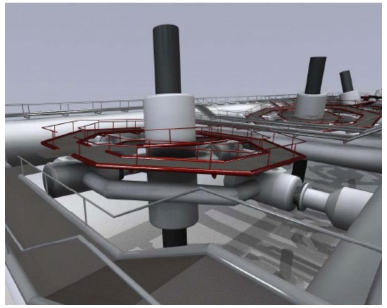
Rotating mass





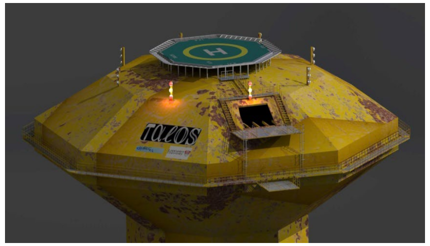
Lancaster WEC Research

- Flexible Bag
- Flounder Array
- Frog
- PS Frog
- Frond
- Yoyo
- Pushmi
- WRASPA
- Seaweaver
- GAIA
- TALOS

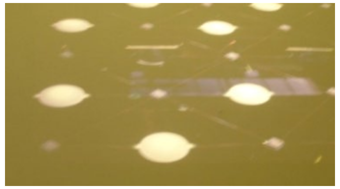

GAIA

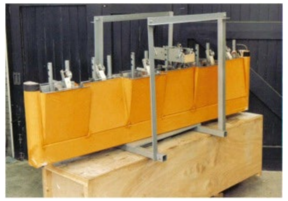

Lancaster Flexible Bag


Yoyo



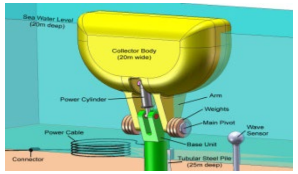
TALOS

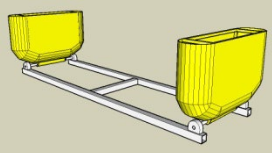

Flounder


Lancaster Flexible Bag Attenuator


Seaweaver

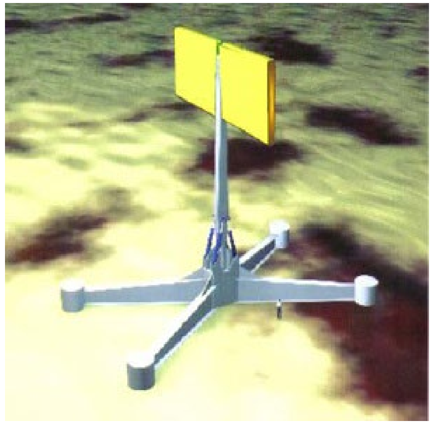

CRM PS Frog


WRASPA

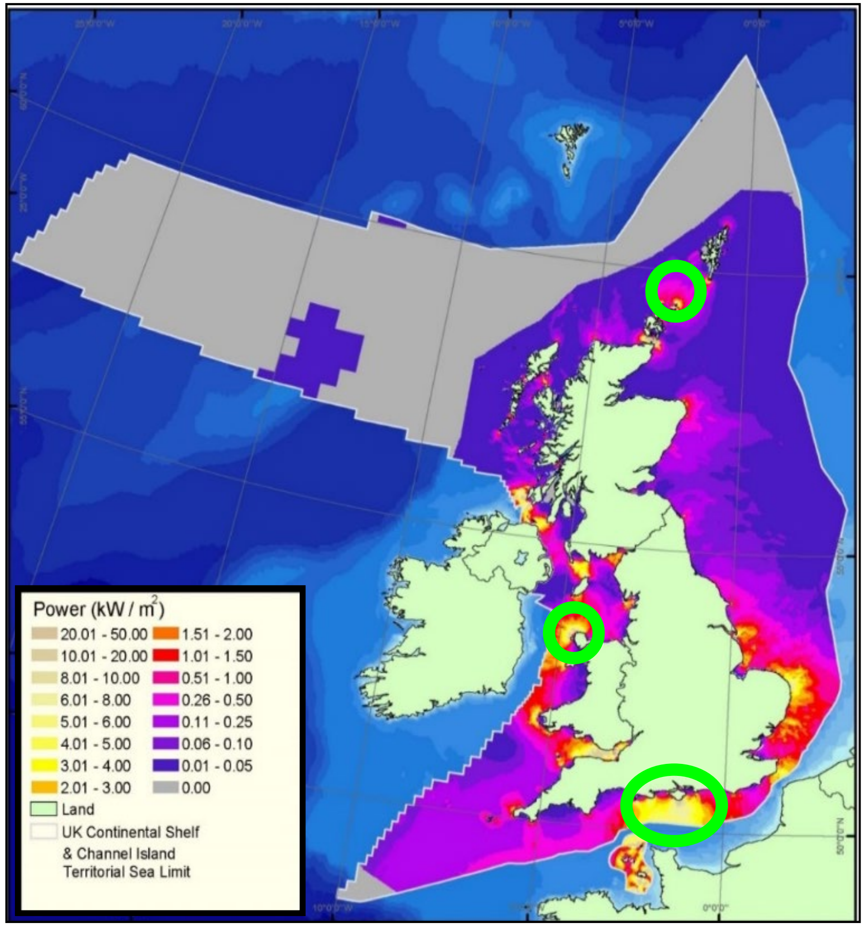

Pushmi


Early PS Frog


PS Frog 5


Frond

Tidal Current Technologies - UK Resource



Tidal Stream

Source – DTI Atlas of Marine Renewable Energy Resources

Main types of Tidal Stream Energy Convertors:

- **Horizontal Axis**
  - Rigidly mounted
  - Floating and Semi-Submerged
- **Vertical Axis**
- **Hydrofoil**
  - Oscillating
  - Translating
- **Venturi Systems**
- **Archimedes Screw**
- **Tidal Kite**
- **Other**

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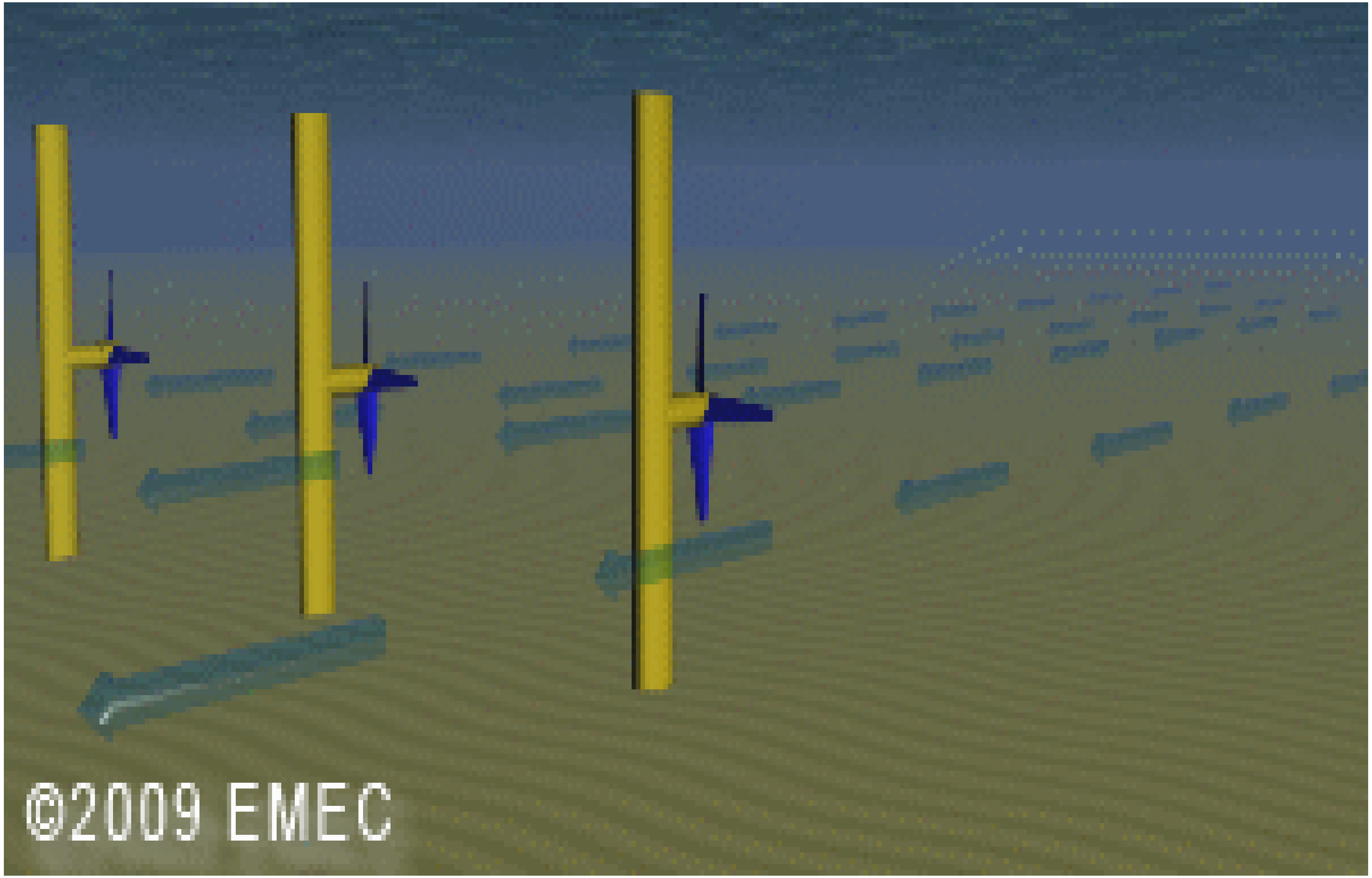
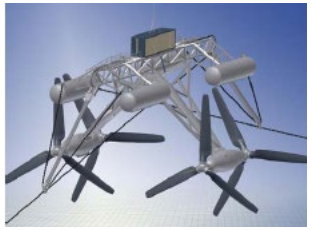
U.S. DEPARTMENT OF ENERGY

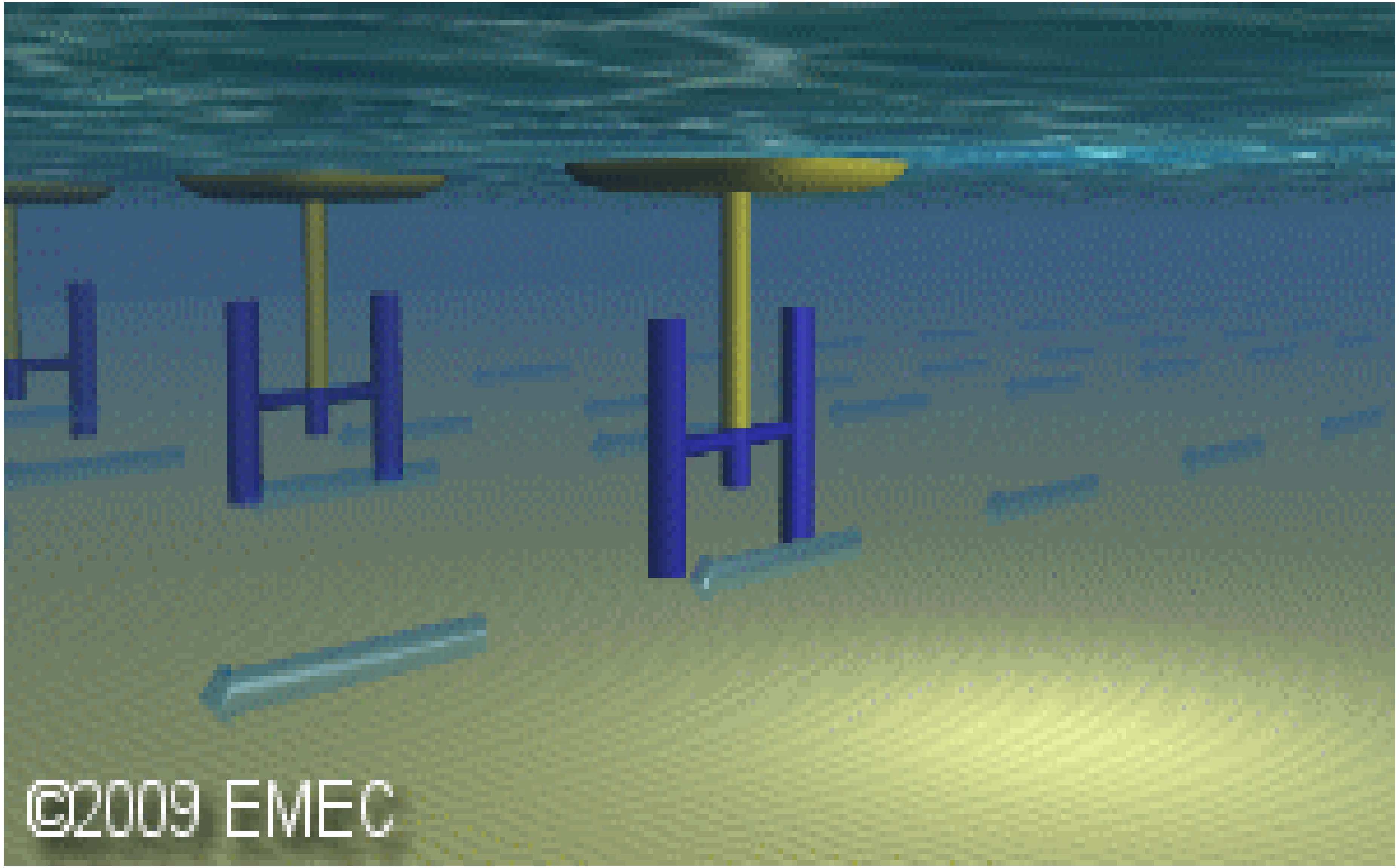
Horizontal axis turbines



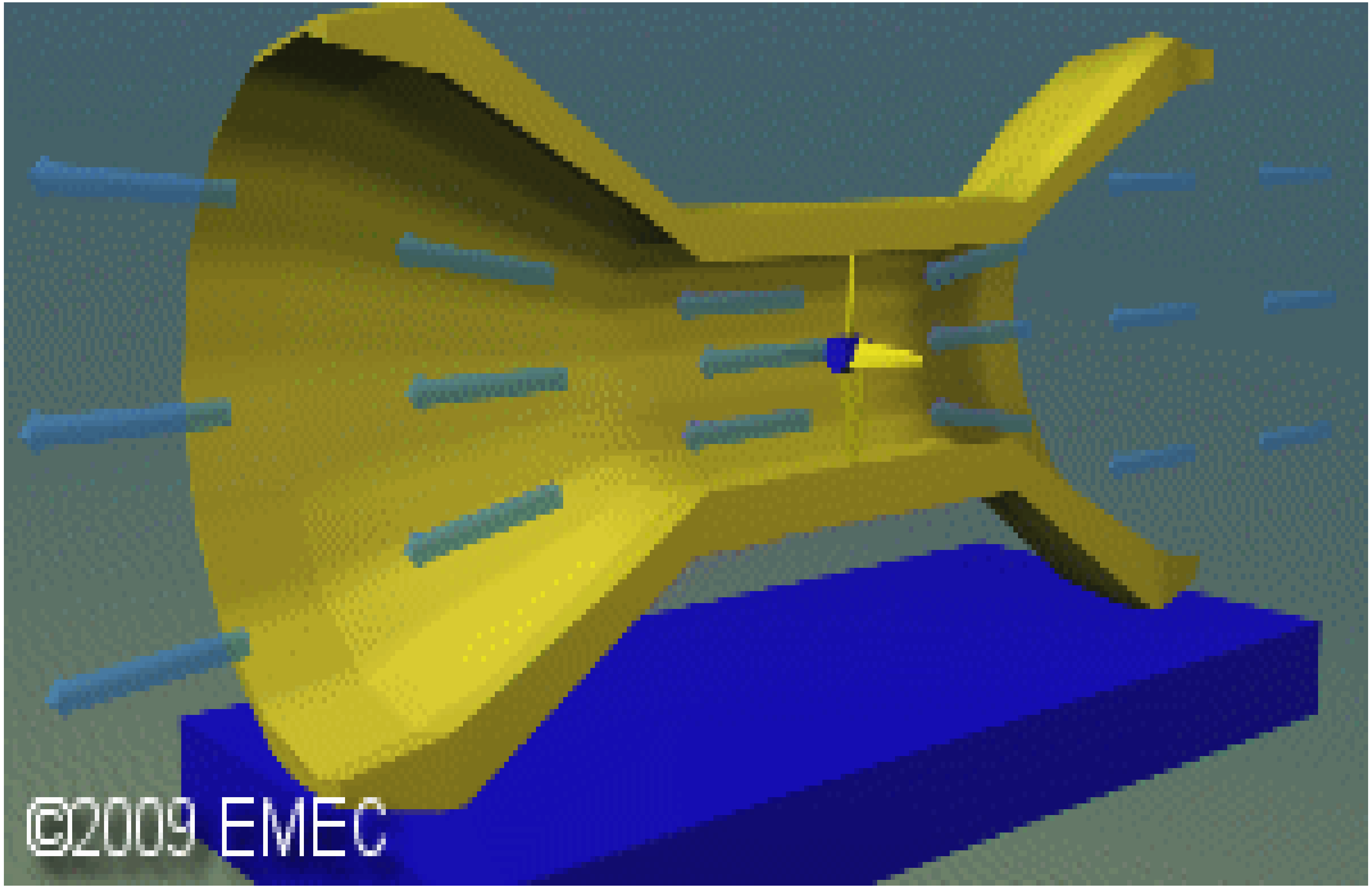
Lancaster University Research with Infinities Global on Tidal Current Technology

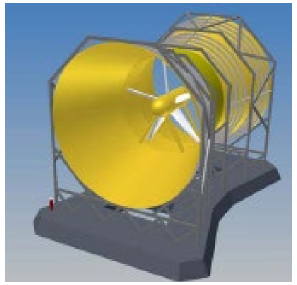


Vertical axis turbines

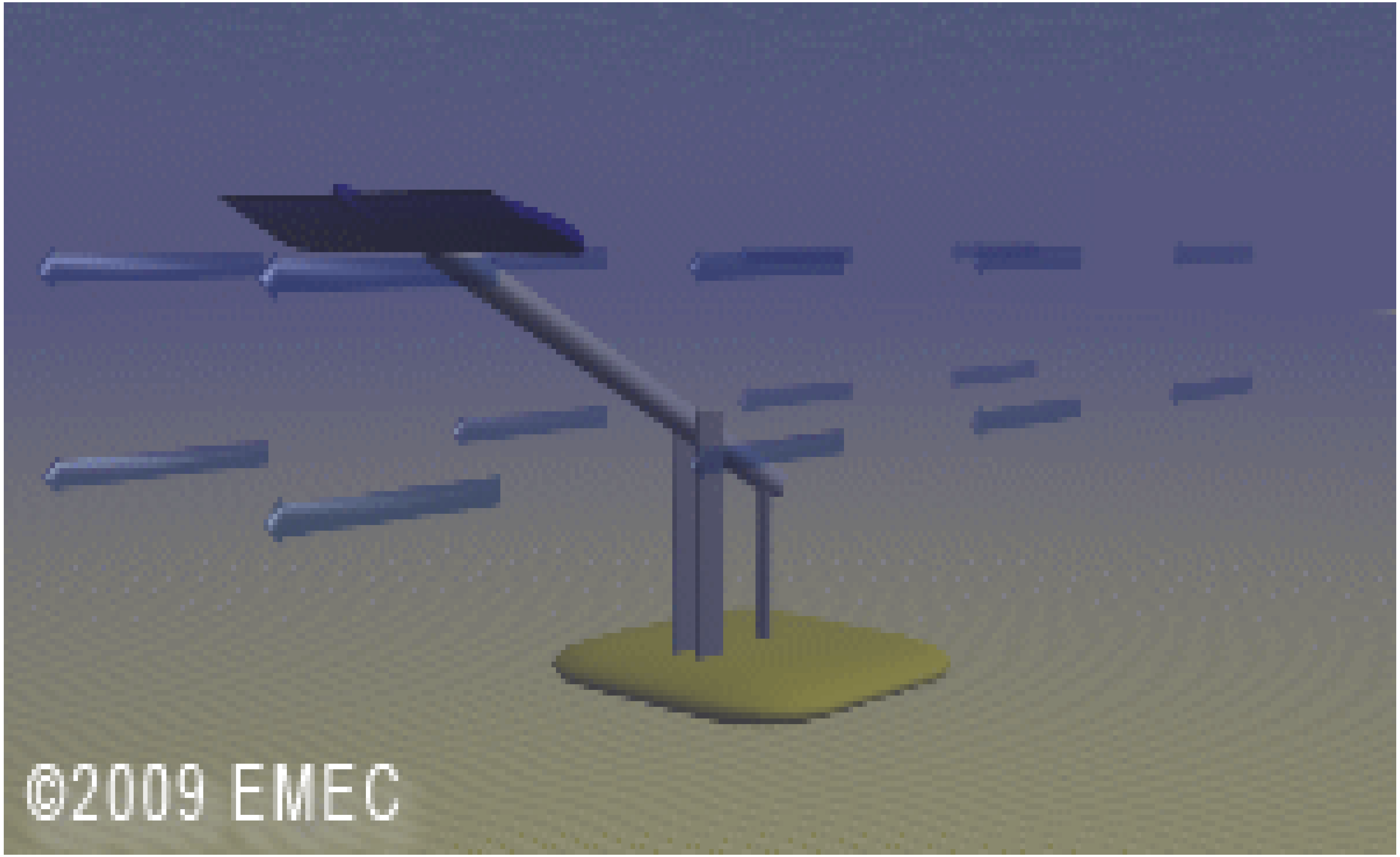


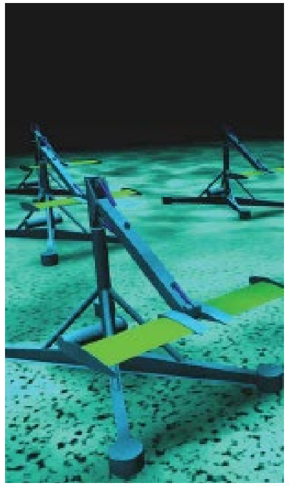
Venturi Effect & Ducted turbines

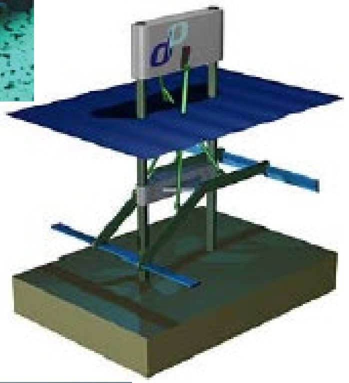




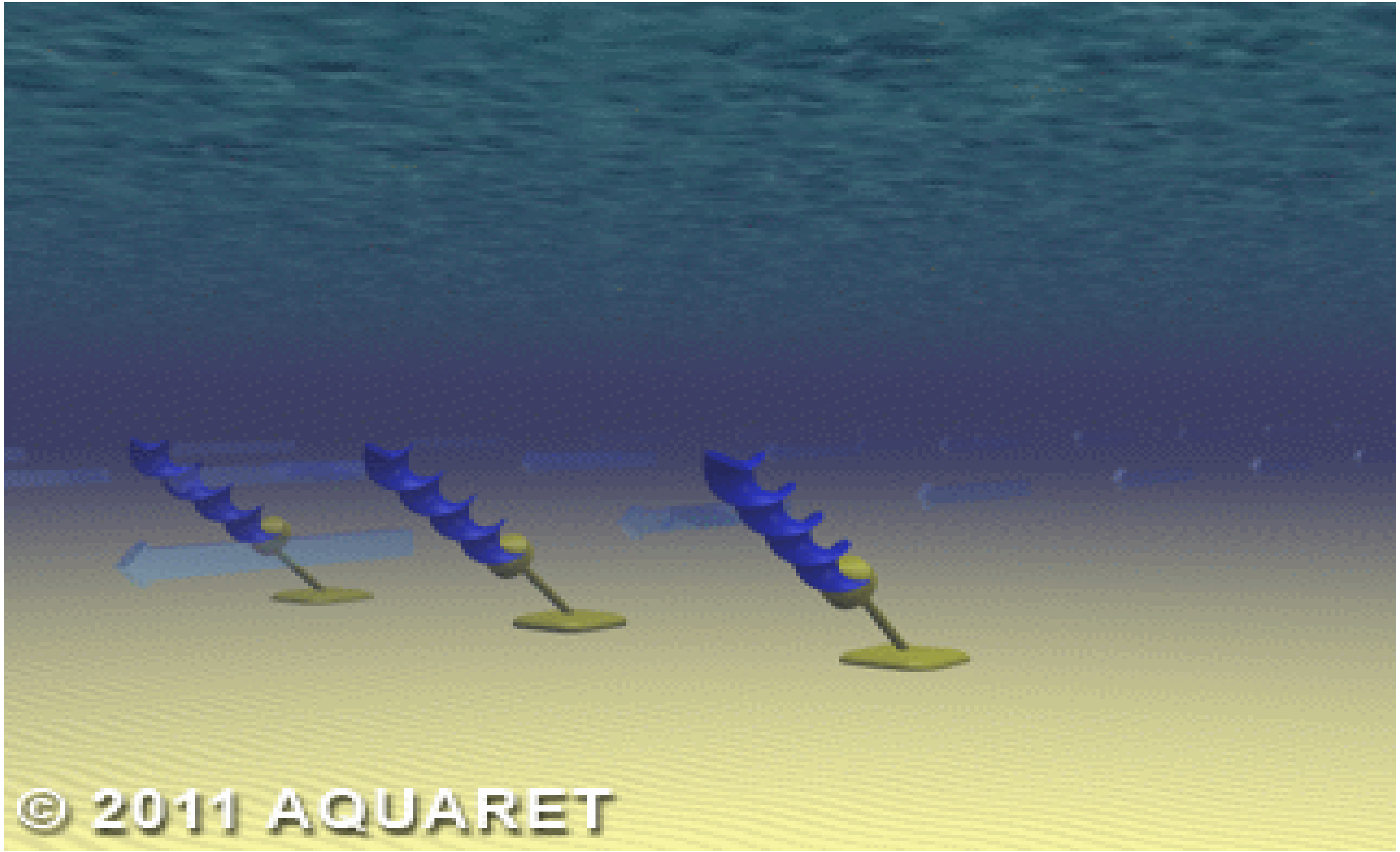
Reciprocating Devices



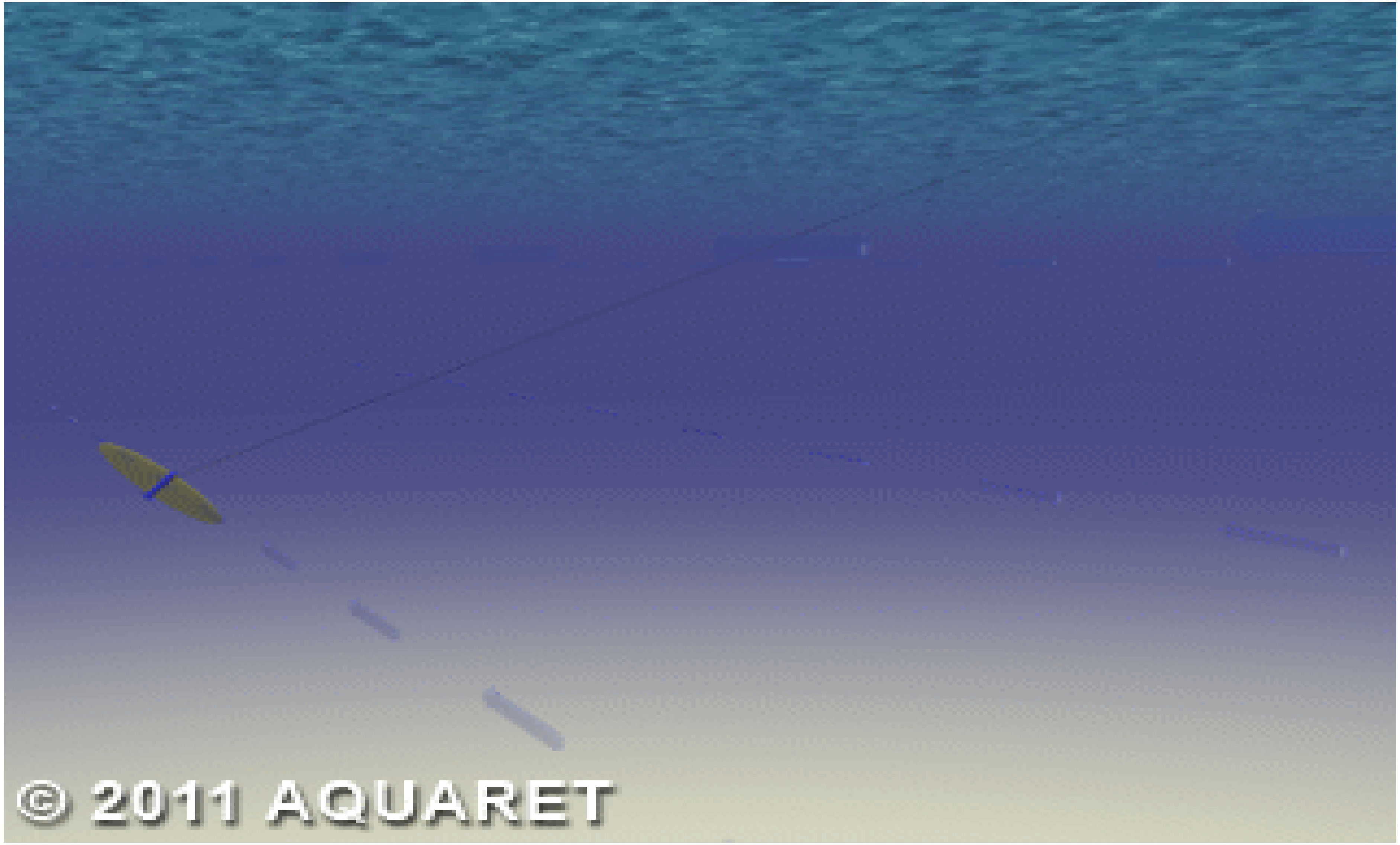




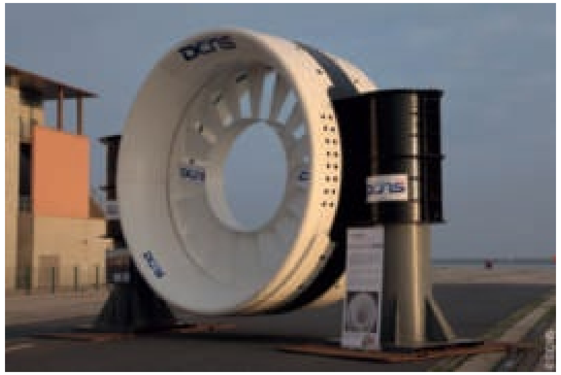
Archimedes Screw



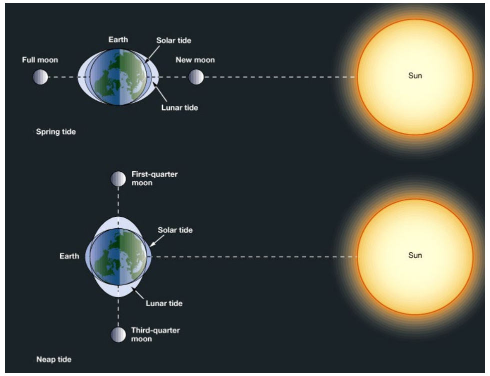
Tidal Kite



Open Centre turbines



Tidal Range Energy Resource



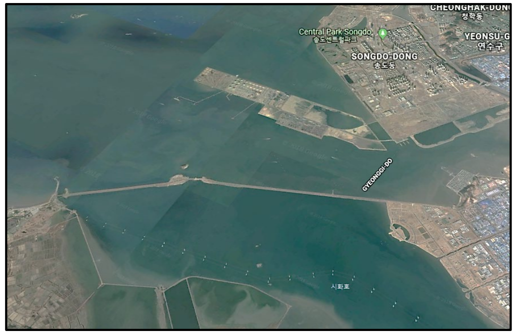
Earth-Moon-Sun Gravity

Neill, S.P., Angeloudis, A., Robins, P.E., Walkington, I., Ward, S.L., Masters, I., Lewis, M.J., Piano, M., Avdis, A., Piggott, M.D. and Aggidis, G., 2018. Tidal range energy resource and optimization–Past perspectives and future challenges. *Renewable energy*, *127*, pp.763-778.

Global References (Tidal Range)

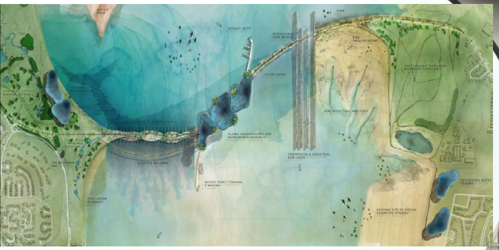
- Existing tidal references world wide include:
  - **La Rance, France, 1967**
    - Alstom Hydro
    - 5.4 m Dia. 24 Turbinesx10 MW
    - 240 MW total capacity
  - **Kislaya Guba, Russia, 1968**
    - 1 Turbine × 0.2 MW
    - 1 Turbine × 1.5 MW
    - 1.7 MW total capacity
  - **Annapolis, Canada, 1980**
    - Andritz VaTech Hydro
    - 7.6 m Dia. Straflo Turbine
    - 1 Turbine x 20 MW
    - 20 MW total capacity
  - **Jiangxia, China, 1980**
    - 1 Turbine × 500KW
    - 1 Turbine × 600KW
    - 3 Turbines × 700KW
    - 3,200 KW total capacity
  - **Sihwa, South Korea, 2011**
    - Andritz Hydro
    - 7.5 m Dia. 10 Turbines x 26 MW
    - 260 MW total capacity

Sihwa, South Korea Tidal Power Plant 2011

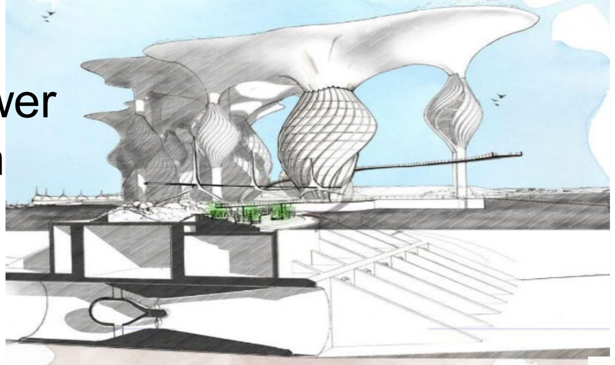


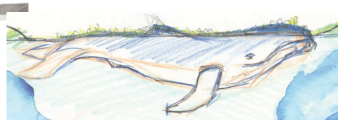
Multi Functional Infrastructure Multidisciplinary Research

International Landmark



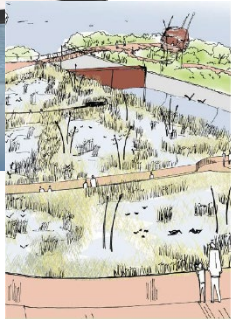
Global Hydropower Research Facilities

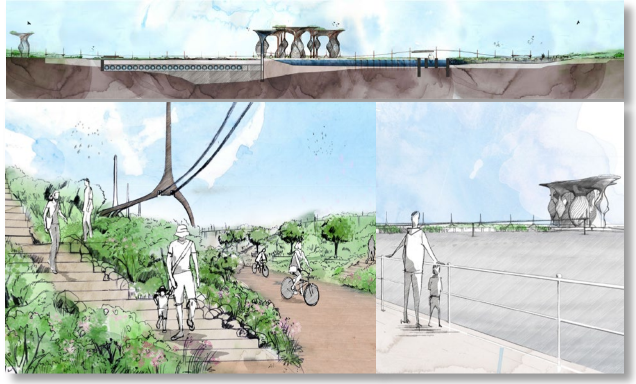




THE GREEN WHALE (2017)

Connecting Communities





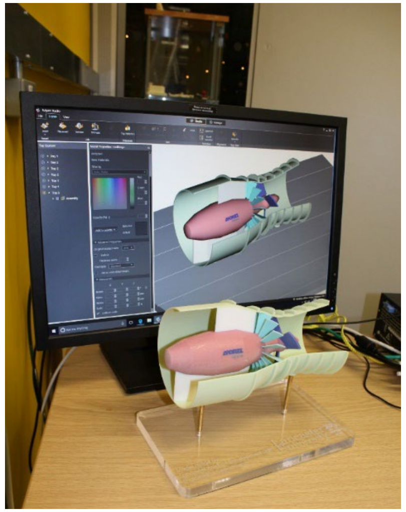
Integrating Wildlife

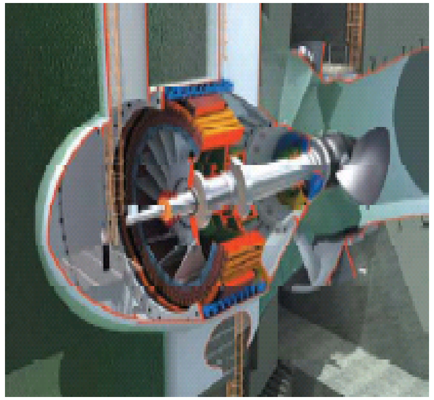
Petley, S., Starr, D., Parish, L., Underwood, Z. and Aggidis, G.A., 2019. Opportunities for tidal range projects beyond energy generation: Using Mersey barrage as a case study. *Frontiers of Architectural Research*, *8*(4), pp.620-633.

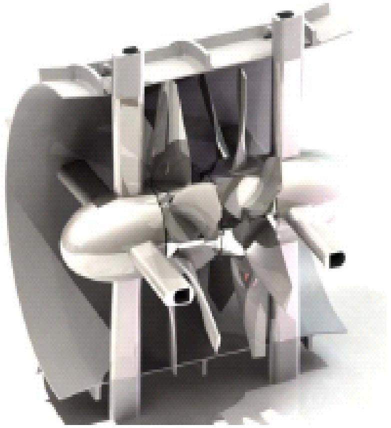
Tidal Technologies

Both forms of energy (potential & kinetic) can be harvested by tidal energy technologies as renewable energy.

Increasing environmental impact



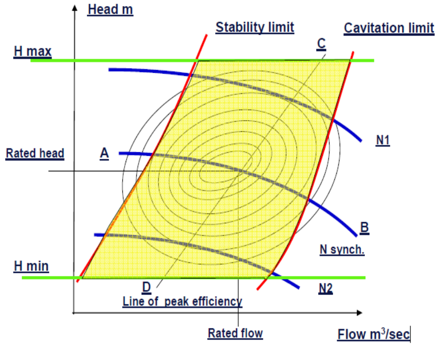




- Uni-directional operation.
- High axial flow speed.
- 50 metre downstream diffuser.
- High solidity rotor.
- Steady flow conditions.
- Deep cavitation submergence.

- Bi-directional operation.
- Low axial flow speed.
- Straight walled support structure.
- Twin low solidity rotors.
- Steady flow conditions.
- Modest cavitation submergence.

- Bi-directional operation.
- Low axial flow speed.
- No enclosing support structure.
- Low solidity rotor.
- Unsteady flow conditions.
- Modest cavitation submergence.

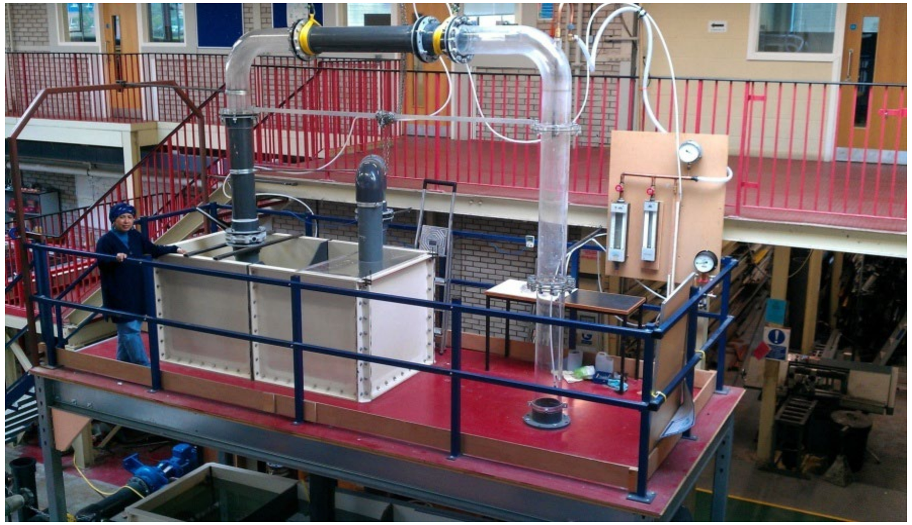


Triple Regulation Turbine (2017)

Decreasing power density

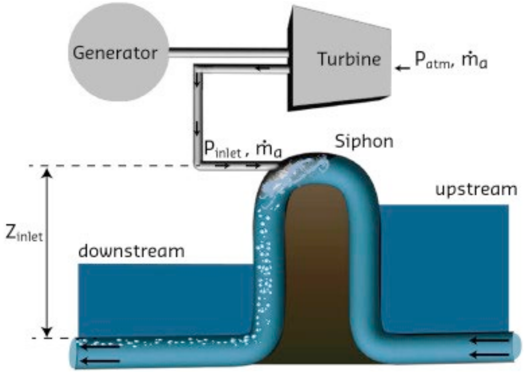
Waters, S. and Aggidis, G., 2016. Tidal range technologies and state of the art in review. *Renewable and Sustainable Energy Reviews*, *59*, pp.514-529.

Lancaster University Tidal Range Technology Research



Lancaster University Research on Environmentally Friendly Solutions using Tidal movements

Lancaster University Research on Low Head Hydro and Archimedes Screw Turbines for Tidal Applications



Holland Estuaries

Smart sea water storage to provide flexibility services to the energy network

TIDETEC
Optimising two-way hydropower

Waters, S. and Aggidis, G., 2016. Tidal range technologies and state of the art in review. *Renewable and Sustainable Energy Reviews*, *59*, pp.514-529.
Waters, S. and Aggidis, G.A., 2015. Over 2000 years in review: Revival of the Archimedes screw from pump to turbine. *Renewable and Sustainable Energy Reviews*, *51*, pp.497-505.
Widden, M.B., French, M.J. and Aggidis, G.A., 2004. Economic energy from low head water by conversion to air pressure. In *IMechE Conference Transactions* (Vol. 6, pp. 41-49).

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EPSRC NHP-WEC
TALOS WEC Research Project

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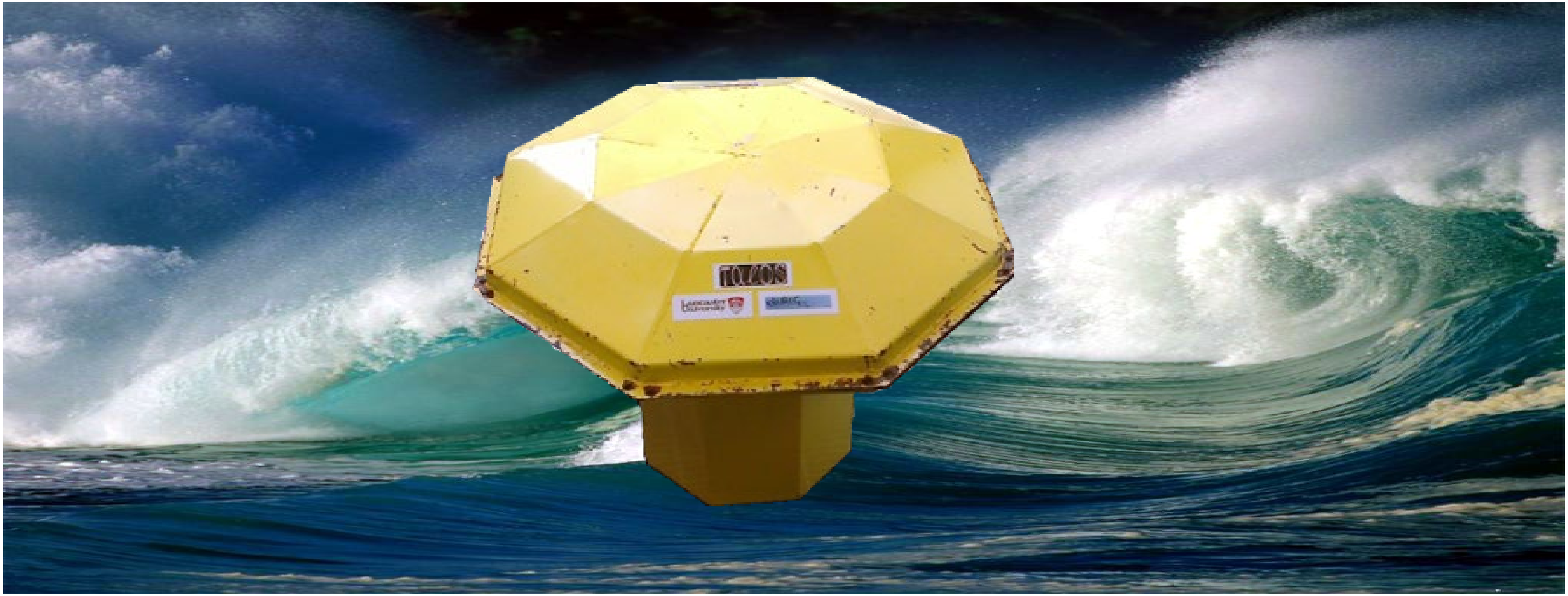

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School of Engineering | Lancaster University

Project Aim & Objectives

- **The project aim:** *Advance WEC technology by developing essential device control and monitoring systems that are integrated with high-fidelity sea state forecasting.*

- **Objectives:**

1. *Concept optimisation – Parameterize hydrodynamic behaviour due to the WEC geometry and PTO design to refine, optimise and maximise performance.*
2. *Operational systems – Investigate and implement sensors and actuators required to develop a condition monitoring system that will improve reliability and survivability, and control methods for the multi-axis PTO system advancing overall conversion efficiency.*
3. *Resource forecasting – Develop machine-learning based forecasting tools to provide both short-term accurate predictions for the operational systems and long-term energy yield predictions for the device across various deployment sites.*
4. *Device deployment potential – Develop a wave-to-wire model to determine the Levelised Cost of Energy (LCOE) at given sites, for both standalone devices and arrays, quantifying the TRL financial baseline performance essential to stimulate commercialisation.*
5. *Marine wave energy development – Develop industrial input and research impact objective, including dissemination and showcasing of all the outputs, to ensure that not only one technology develops but that the solutions proposed will benefit the wider energy community.*

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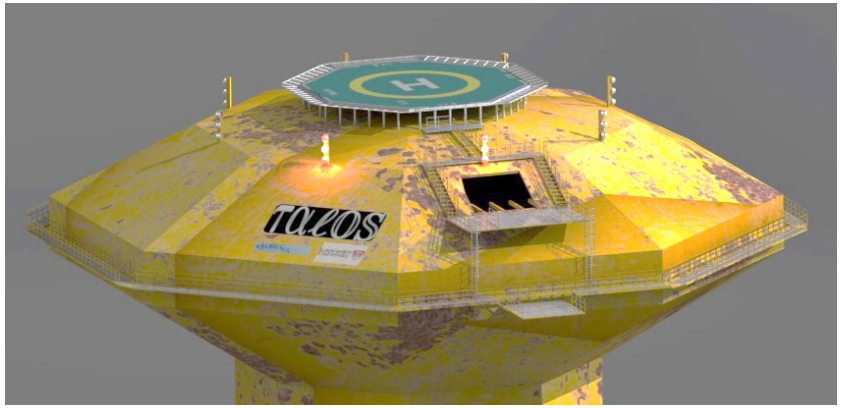
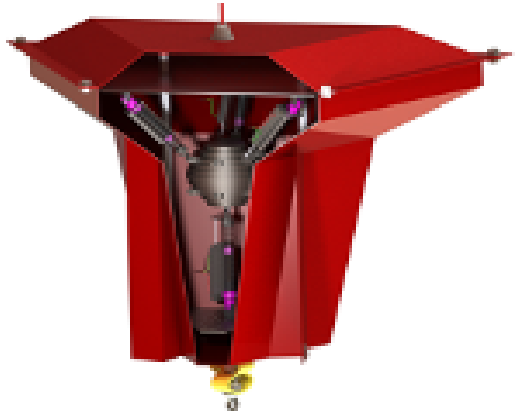
SmartWave

TALOS WEC - Advisory Board

TALOS WEC – Multi Axis Point Absorber Style WEC completely enclosed with internal inertial mass using Hydraulic Cylinders or Linear Generators PTO





EMEC ORKNEY
THE EUROPEAN MARINE ENERGY CENTRE LTD

NREL
Transforming ENERGY

DNV

CATAPULT
Offshore Renewable Energy

aura

THE DEEP
For conservation, not profit

AMRC
ADVANCED MANUFACTURING RESEARCH CENTRE

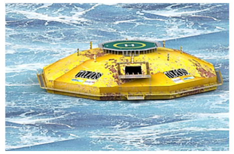
Work Package Tasks Timeline – Project Start: August 2021

Tasks	Quarter	1	2	3	4	5	6	7	8	9	10	11	12
WP1: Concept optimisation													
Experimental and numerical hydrodynamic analysis													
Geometric Optimisation													
Power Take-Off Design													
WP2: Survivability, Reliability and Optimised Control of Devices in the Marine Environment													
Smart sensor and data acquisition system													
Intelligent condition monitoring													
Predictive maintenance													
Optimised control strategy													
WP3: Sea state forecasting and resource evaluation													
Resource characterisation													
WEC efficiency calculations in wave tanks													
Array effects													
WP4 – Validation and Cost of Energy													
Validation and demonstration of development													
Array deployment													
Levelised Cost of Energy													

EPSRC NHP-WEC Research Project Website

TALOS wave energy converter (LU):

The research proposed is simultaneously generic while significantly contributing to the development of a concept device that has shown potential, namely the multi-axis TALOS that has been developed and tank tested at Lancaster University.



TALOS is a novel multi-axis moving parts, and the internal PTO system is made up of an inertial mass (a ball) with hydraulic cylinders that attach it to the hull. The motion of the ball moves the hydraulic cylinders causing them to pump hydraulic fluid through a circuit, thus to generate electricity i.e. an inertial mass PTO approach.

Key strengths of TALOS device include:

- Fully enclosed wave energy converter, so to avoid the harsh sea environments on the energy conversion system;
- The arrangement of the rams allows for the ball to move in multiple directions, allowing energy to be captured from multiple degrees of freedom;
- The flow of hydraulic fluid will change as the ball's motion changes, so an internal hydraulic smoothing circuit is utilised to regulate the output.

SmartWave (UoH):

SmartWave is a tool capable of deriving high resolution sea state conditions from satellite images using machine learning. It integrates recent advances in all-weather satellite monitoring to map and study the temporal and spatial distribution of sea surface wave characteristics.

Key strengths:

- based on a novel forecasting methodology;
- capable of resolving sea state within offshore windfarms for sector O&M logistics.

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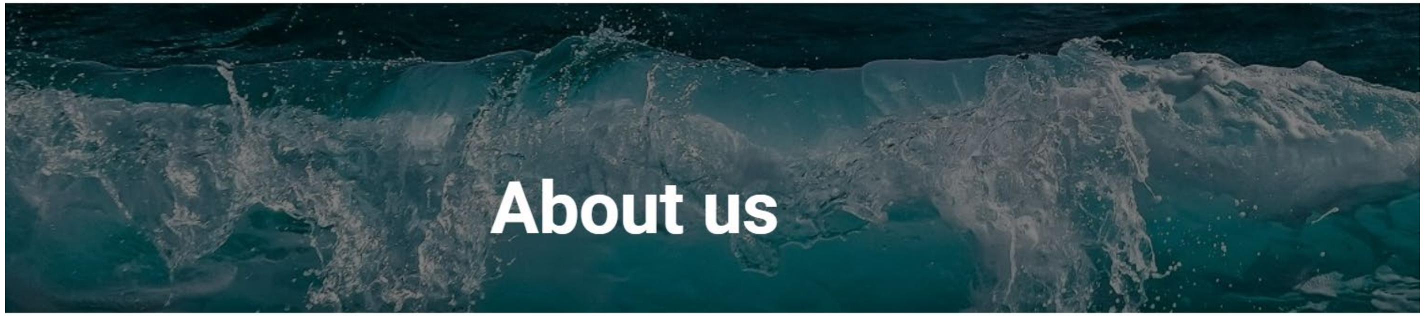
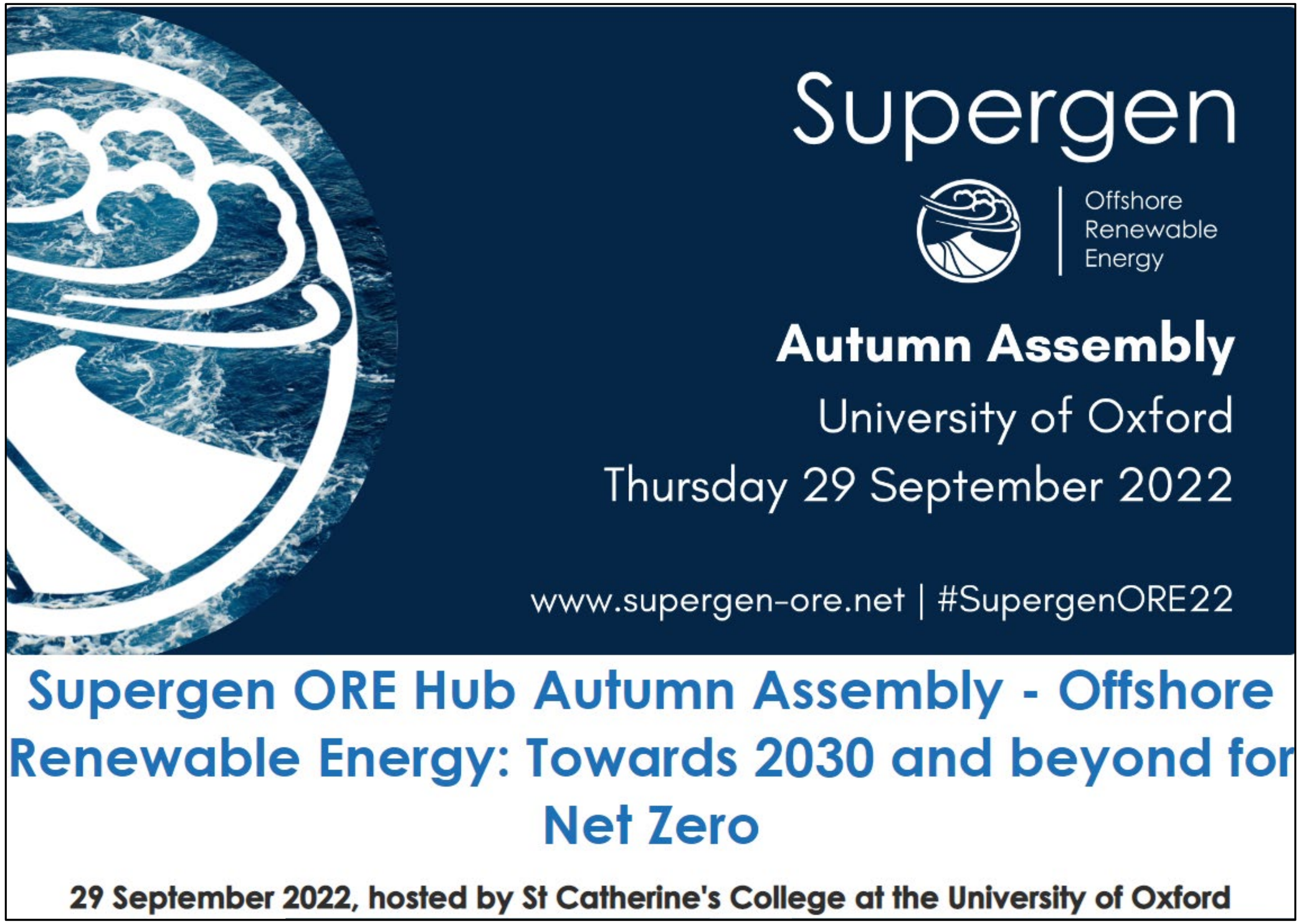


The NHP-WEC project aims to advance data-driven monitoring and control in connection to both device technology and sea state predictions for WEC arrays, combining the TALOS technologies of Lancaster University (LU) and the SmarWave technologies of University of Hull (UoH). The NHP-WEC project aims to optimise the design of the wave energy converter and the PTO system (TALOS) in response to time-varying inputs from waves (SmartWave). as such, the operational conditions, including wave characteristics, must be quantified to estimate dynamic loads, constraining manufacturing techniques and materials, so to improve wave energy production as well as the survivability of the wave energy system.

[EPSRC NHP-WEC project: A TALOS and SmartWave Project (lancs.ac.uk)]

Supergen ORE – Sept 2022

- Supergen ORE Autumn Assembly September 2022
  - University of Oxford
- Offshore Renewable Energy: Towards 2030 and beyond for Net Zero
  - St. Catherine’s College
- Invited Presentations Included:
  - NHP-WEC TALOS Project



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Outputs & DNV SESAM Software

- PAPERS
  - Hydrodynamic studies of floating structures: Comparison of wave-structure interaction modelling, Ocean Engineering, Vol. 249, 110878.
  - Time-domain implementation and analyses of multi-motion modes of floating structures, Journal of Marine Science and Engineering, Vol. 10, 662. https://doi.org/10.3390/jmse10050662
  - A Preliminary Study on Identifying Biomimetic Entities for Generating Novel Wave Energy Converters. Energies, 15(7), p.2485.

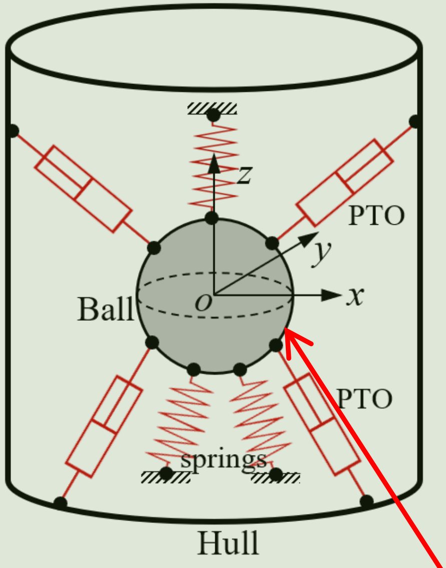
- BOOK
  - Environmental Fundamentals of Wave Energy Conversions: The Dynamics of the Wave-Structure Interactions and Wave Energy Optimisation, Eliva Press.

- DNV SESAM SOFTWARE
  - Collaboration with AUTH & IHU Universities (Greece)
  - Building time-domain model using DNV SESAM code
  - For comparisons with in-house time-domain model

WP1 - Implementation & Comparison of TALOS WEC

Equations for hull motion

$$\begin{cases}(m_s + A_{11})\ddot{x}_{s1}(t) + \sum_{j=1}^{6}\int_0^t K_{1j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s1}x_{s1}(t) = F_1^{exc}(t) - F_{pto1}(t) - F_{spr1}(t) \\ (m_s + A_{22})\ddot{x}_{s2}(t) + \sum_{j=1}^{6}\int_0^t K_{2j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s2}x_{s2}(t) = F_2^{exc}(t) - F_{pto2}(t) - F_{spr2}(t) \\ (m_s + A_{33})\ddot{x}_{s3}(t) + \sum_{j=1}^{6}\int_0^t K_{3j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s3}x_{s3}(t) = F_3^{exc}(t) - F_{pto3}(t) - F_{spr3}(t) \\ (I_{s44} + A_{44})\ddot{x}_{s4}(t) + \sum_{j=1}^{6}\int_0^t K_{4j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s4}x_{s4}(t) = F_4^{exc}(t) - M_{pto1}(t) - M_{spr1}(t) \\ (I_{s55} + A_{55})\ddot{x}_{s5}(t) + \sum_{j=1}^{6}\int_0^t K_{5j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s5}x_{s5}(t) = F_5^{exc}(t) - M_{pto2}(t) - M_{spr2}(t) \\ (I_{s66} + A_{66})\ddot{x}_{s6}(t) + \sum_{j=1}^{6}\int_0^t K_{6j}(t-\tau)\dot{x}_{sj}(\tau)d\tau + C_{s6}x_{s6}(t) = F_6^{exc}(t) - M_{pto3}(t) - M_{spr3}(t)\end{cases}$$



2-body system:
Hull + Ball

$$\begin{cases}m_b\ddot{x}_{b1}(t) = F_{pto1}(t) + F_{spr1}(t) \\ m_b\ddot{x}_{b2}(t) = F_{pto2}(t) + F_{spr2}(t) \\ m_b\ddot{x}_{b3}(t) = F_{pto3}(t) + F_{spr3}(t) \\ I_{bxx}\ddot{x}_{b4}(t) = M_{pto1}(t) + M_{spr1}(t) \\ I_{byy}\ddot{x}_{b5}(t) = M_{pto2}(t) + M_{spr2}(t) \\ I_{bzz}\ddot{x}_{b6}(t) = M_{pto3}(t) + M_{spr3}(t)\end{cases}$$

Equations for ball motion

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WP1 - International collaborations

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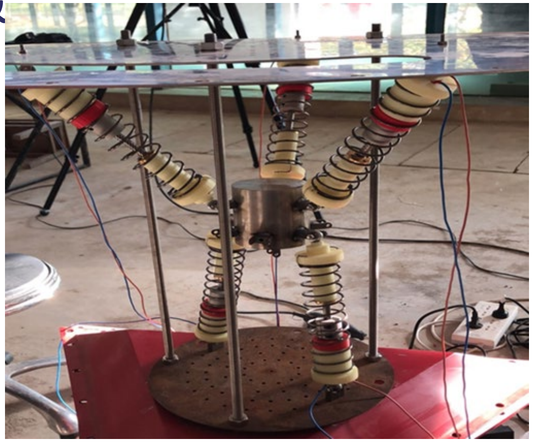
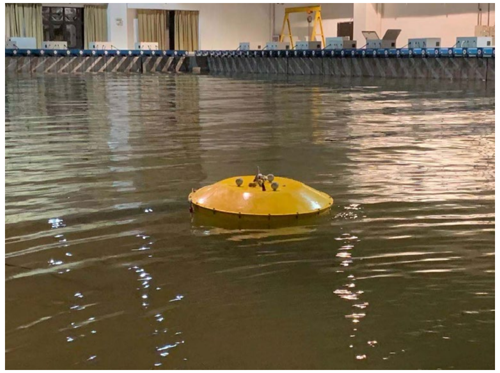
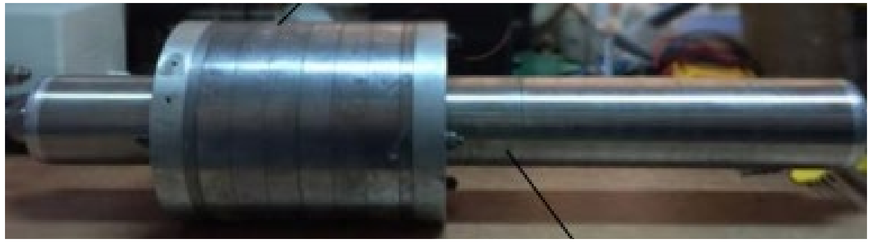
- **NREL & Sandia NL (USA),** a TEAMER funding support approved to build time-domain modelling for TALOS WEC using WEC-SIM facility
- **AUTH & IHU Universities (Greece)** are building time-domain model using DNV SESAM code (for comparisons with in-house time-domain model)
- **Zhejiang University (China),** experimental testing & computational time-domain model of TALOS WEC



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WP2 - Survivability Reliability & Optimised Control of Devices in the marine environment

Lancaster University

Tasks	Quarter 1	2	3	4	5	6	7	8	9	10	11	12
WP2: Survivability, Reliability and Optimised Control of Devices in the Marine Environment												
Smart sensor and data acquisition system				■	■	■						
Intelligent condition monitoring						■	■	■				
Predictive maintenance								■	■	■		
Optimised control strategy										■	■	■

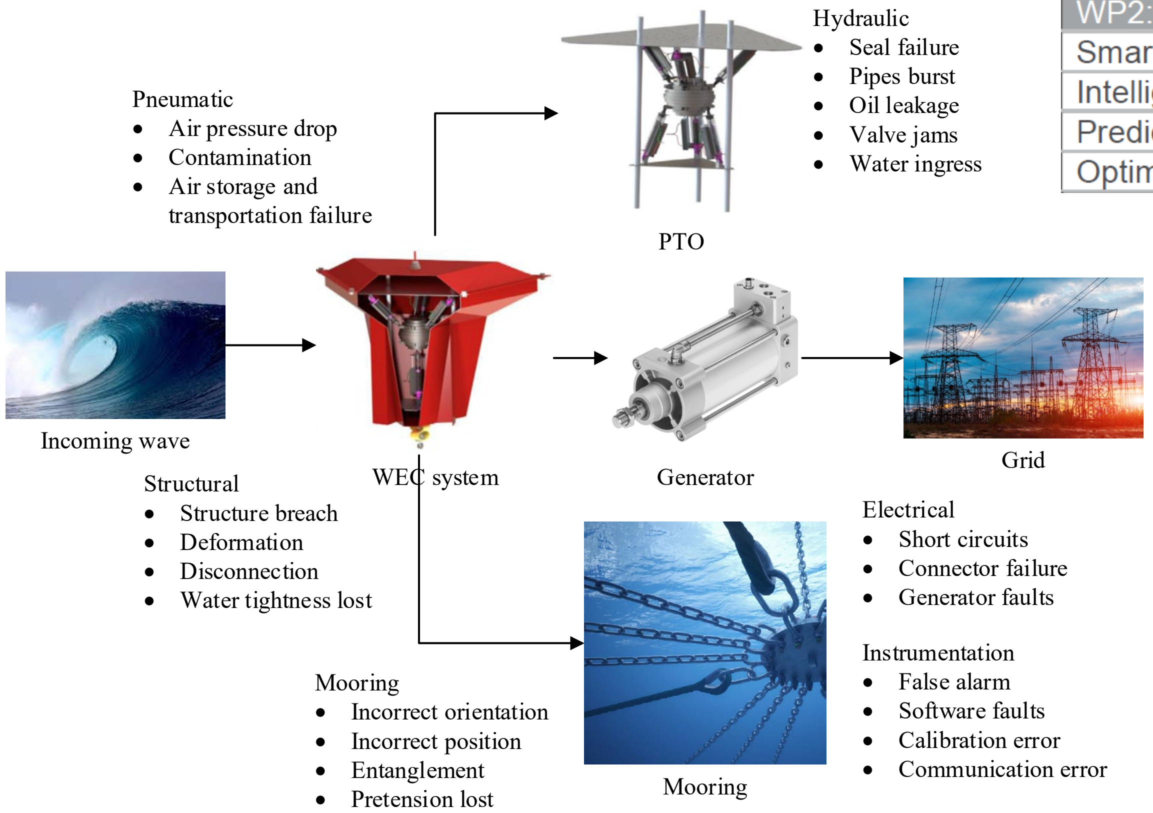

Figure. 1 Common failure modes of WEC

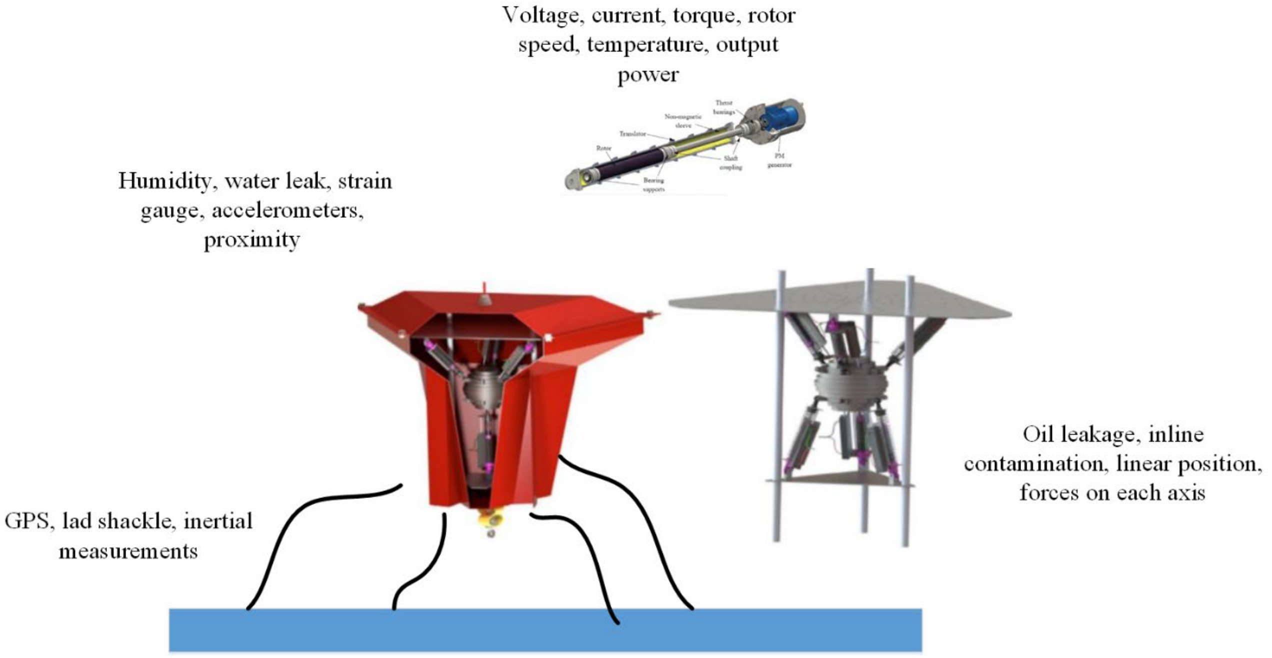

Figure. 2 Sensing system of the TALOS WEC

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WP2 - Survivability Reliability & Optimised Control of Devices in the marine environment

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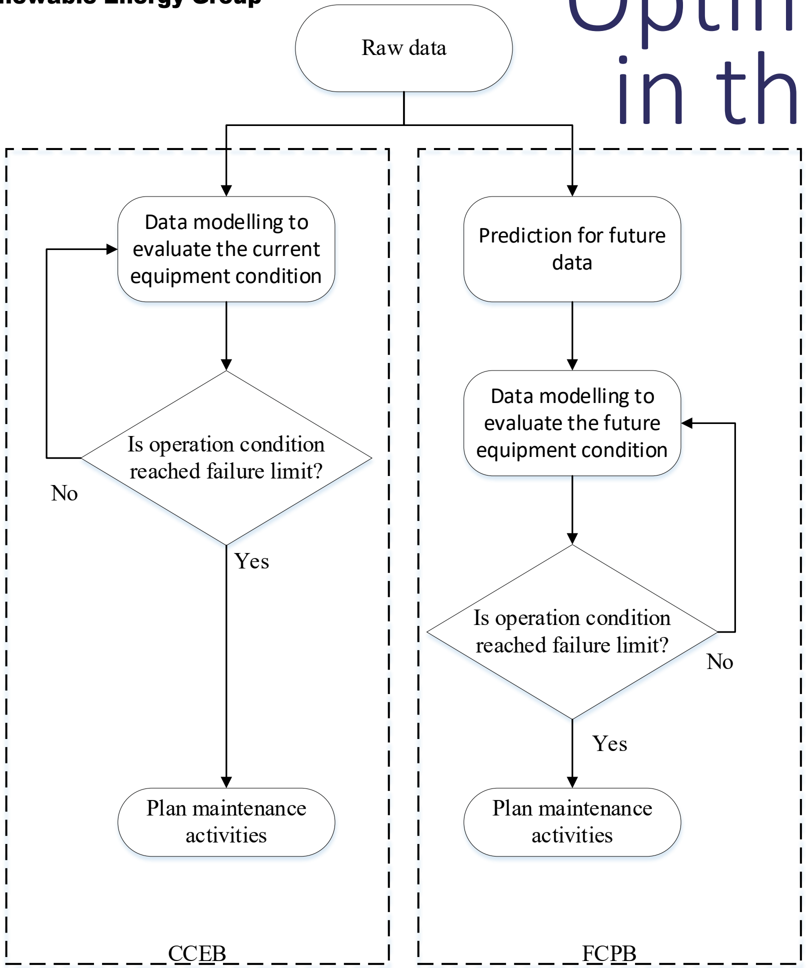


Figure. 3 Frameworks of current condition evaluation-based (CCEB) and future condition prediction-based (FCEB) maintenance strategies

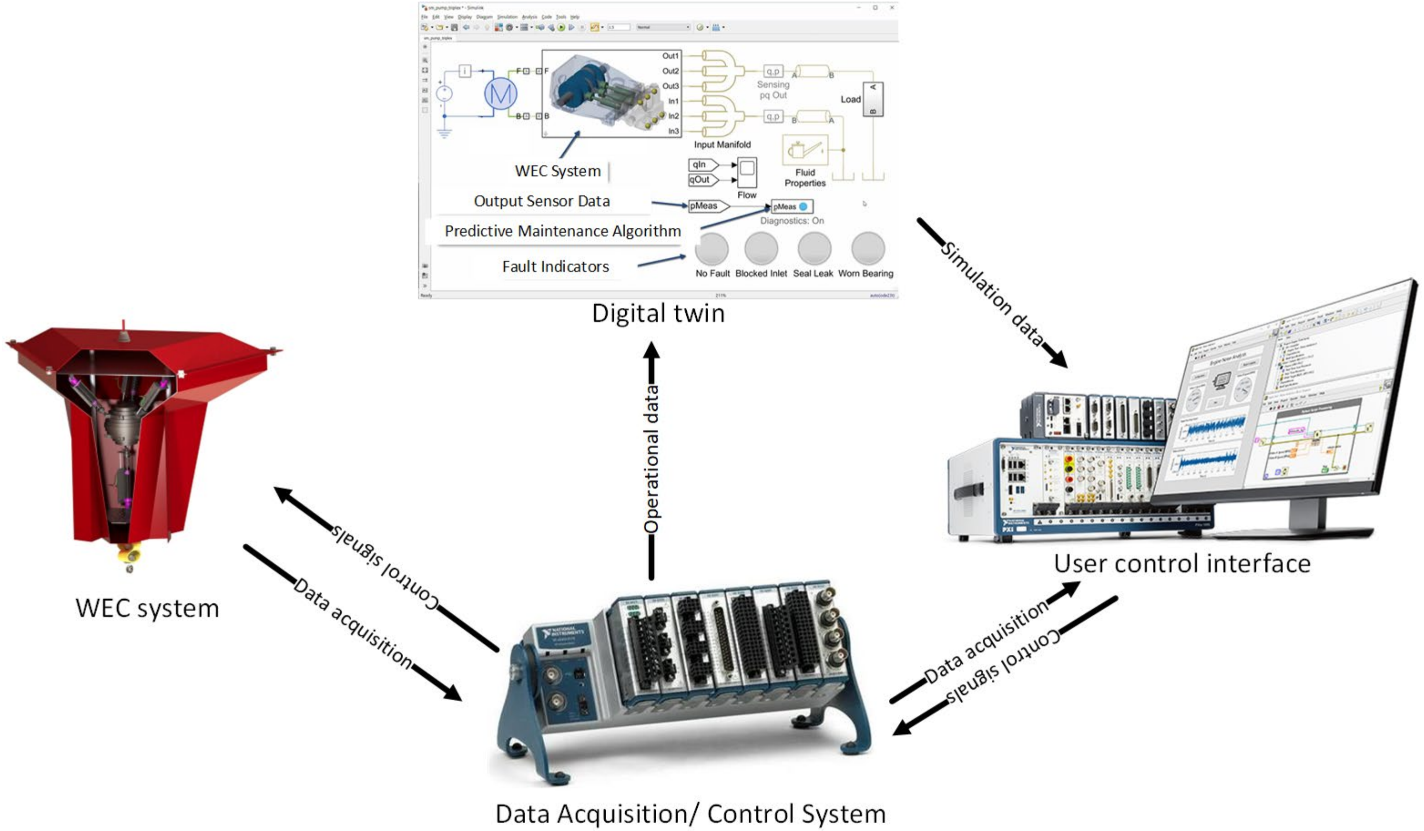


Figure. 4 Optimised control strategies

WP3 - **SmartWave** - High Accuracy & High Spatial Fidelity Wave Prediction

Lancaster University Renewable Energy Group

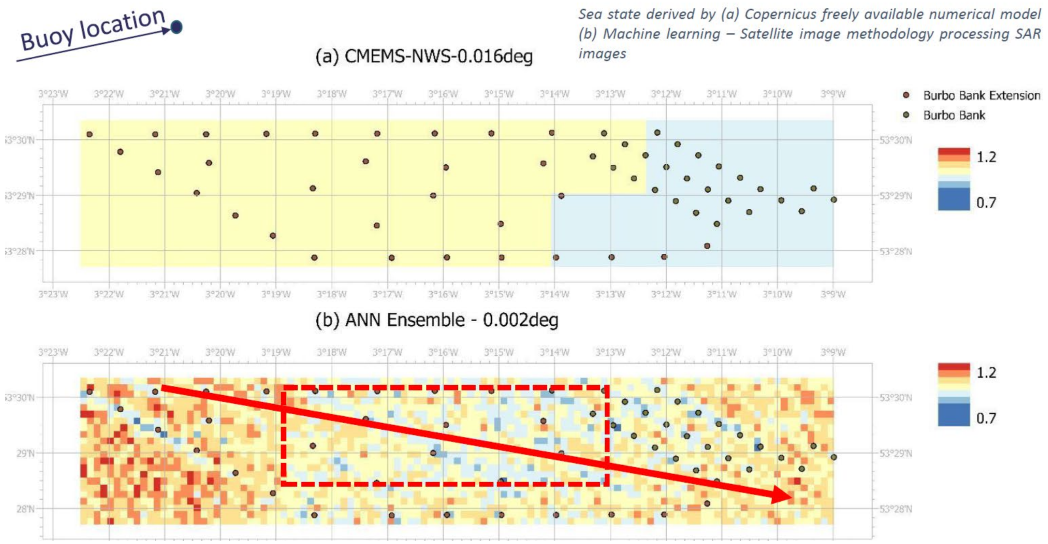
Artificial Intelligence (Artificial Neural Network – ANN and Convolutional Neural Network – CNN) will be advanced to estimate key oceanographic parameters i.e. wave height, direction, frequency, and speed. State-of-the-art remote sensing monitoring and in situ data from European Space Agency satellite Sentinel 1 (Synthetic Aperture Radar – SAR) will be utilised, whilst access to high-fidelity data from the Cefas WaveNet buoys will provide ground truth data for validation.

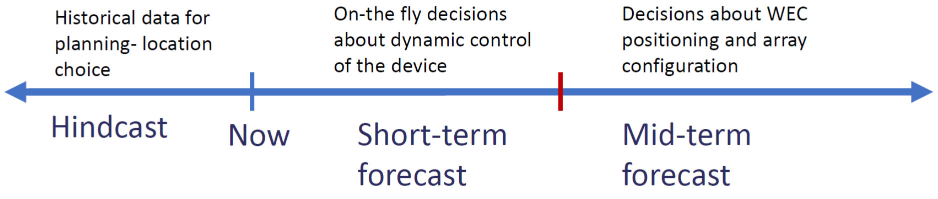
Example results – Burbo Bank

Comparison of Sea state conditions at 2/4/2019 06:32:16am

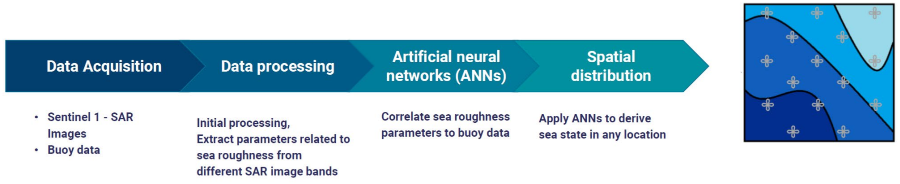
Buoy data: 0.89m (6:30am) – 1.07m (7:00am) | **Numerical model at the buoy: 0.92m** | **ANN Ensemble: 0.95m**

- Same trend of significant wave height for both hindcasts
- Higher resolution for machine learning-satellite image methodology
- Possible to identify pattens like sheltering in the inner wind turbines compared to the ones that are at the edge of the wind farm.





ANN based system



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WP3 - CNN based system

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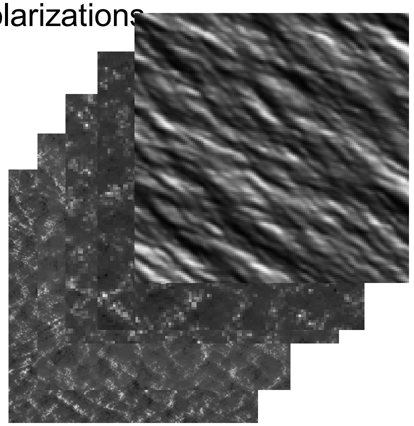
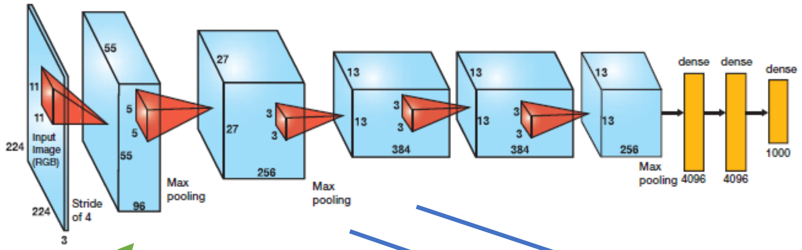
Deep learning

SAR imagery synthetic database creation

Different parameters:
wind directions
wind speeds
fetch size
incidence angles
polarizations



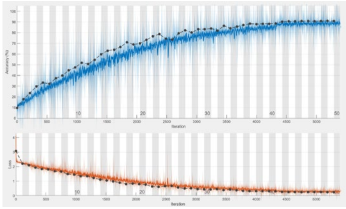
Training CNN (AlexNet)



Strategies:
Training from scratch
Transfer learning with real data

Automated classification and estimation of sea state parameters:
wave height
direction
frequency
speed

Iter	Eval result	Objective	Objective runtime	BestSoFar (observed)	BestSoFar (estim.)	InitialLearn-Rate	Momentum	L2Regulariza-tion
1	Best	1	3105.1	1	1	0.024555	0.43595	5.0777e-06
2	Best	0.40836	3103.3	0.40836	0.40836	9.5243e-05	0.87476	1.0475e-08
3	Accept	0.45364	3104.1	0.40836	0.40836	0.0006379	0.12174	2.6151e-09
4	Accept	1	3074.6	0.40836	0.40836	0.098715	0.94202	0.0067696
5	Accept	0.83931	3114.9	0.40836	0.40836	1.0005e-05	0.15452	2.7178e-10
6	Accept	0.5506	3106.5	0.40836	0.40836	0.0002163	0.53962	0.00095463
7	Accept	0.5797	3106.9	0.40836	0.40836	0.0001935	0.50806	1.1739e-10
8	Best	0.055592	3105.1	0.055592	0.055592	0.00021575	0.97865	0.001066
9	Best	0.038762	3110.5	0.038762	0.038762	0.00044832	0.97996	1.0937e-10
10	Accept	0.049403	3103.5	0.038762	0.038762	0.00029338	0.97773	1.2902e-05
11	Accept	0.56862	3103.2	0.038762	0.038762	1.0139e-05	0.97907	1.3726e-10
12	Accept	0.041585	3104.7	0.038762	0.038762	0.0011907	0.97933	1.0402e-10
13	Accept	0.047774	3103.3	0.038762	0.038762	0.0011278	0.92341	9.8841e-08
14	Accept	0.039088	3101	0.038762	0.038762	0.00083718	0.9782	1.0341e-09
15	Accept	0.042888	3102.4	0.038762	0.038762	0.0024474	0.83733	2.9464e-09
16	Best	0.035505	3101	0.035505	0.035505	0.0021245	0.89919	[illegible]
17	Accept	0.044517	3101	0.035505	0.035505	0.0018115	0.86293	1.7411e-08
18	Accept	0.038328	3100.4	0.035505	0.035505	0.0031433	0.88702	0.0047809
19	Accept	0.039522	3106.2	0.035505	0.035505	0.0026048	0.87974	2.1716e-10
20	Accept	0.038979	3102.9	0.035505	0.035505	0.0027015	0.96409	0.0039482
Iter	Eval result	Objective	Objective runtime	BestSoFar (observed)	BestSoFar (estim.)	InitialLearn-Rate	Momentum	L2Regulariza-tion
21	Accept	0.078827	3101.6	0.035505	0.035505	0.0020347	0.62307	0.0072111
22	Accept	0.04202	3102.3	0.035505	0.035505	0.00058528	0.97863	0.0093505
23	Accept	0.045603	3105.2	0.035505	0.035505	0.0031791	0.74056	0.0019972
24	Accept	0.11574	3105.5	0.035505	0.035505	0.0032981	0.10648	3.5449e-07
25	Accept	1	3074.8	0.035505	0.035505	0.49679	0.10751	9.3844e-05
26	Accept	0.042562	3107.1	0.035505	0.035505	0.0018726	0.97489	5.3037e-06
27	Accept	0.067752	3102	0.035505	0.035506	0.0034142	0.40467	0.00048835
28	Accept	0.091531	3094	0.035505	0.035506	0.005488	0.97137	0.00013895
29	Accept	0.1266	3107.5	0.035505	0.035506	0.0023768	0.27592	0.0096563
30	Accept	0.04126	3102	0.035505	0.035506	0.0045904	0.65601	0.0022301



Bayesian optimization to find optimal network hyperparameters

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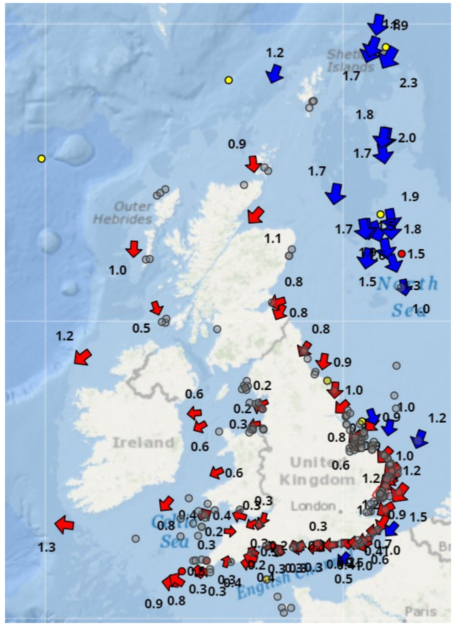
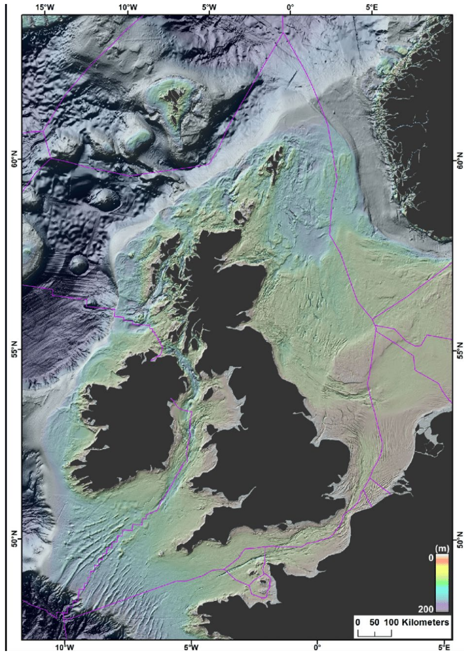
WP3 - Mapping of wave power for shallow, intermediate, and deep-water areas

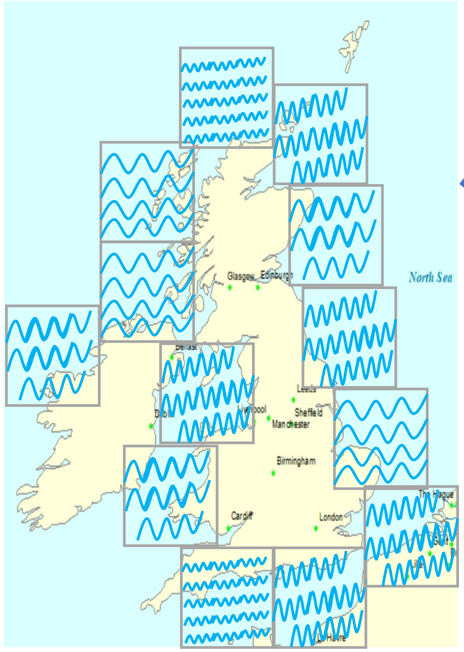
Cefas WaveNet buoys



Bathymetry offshore model of the UK (EMODnet and GEBCO)



Determination of wave type dominance



Mapping of waves based on simulation

TMA for shallow

JONSWAP for deep

Wave power

Model of the mean wavelength

Hindcast wave parameters (1980-2022)
Total: Hs, Tp, Tz, Dp
Components: Tm_w, Tm_s1, T_ms2, Dw, Ds1, Ds2

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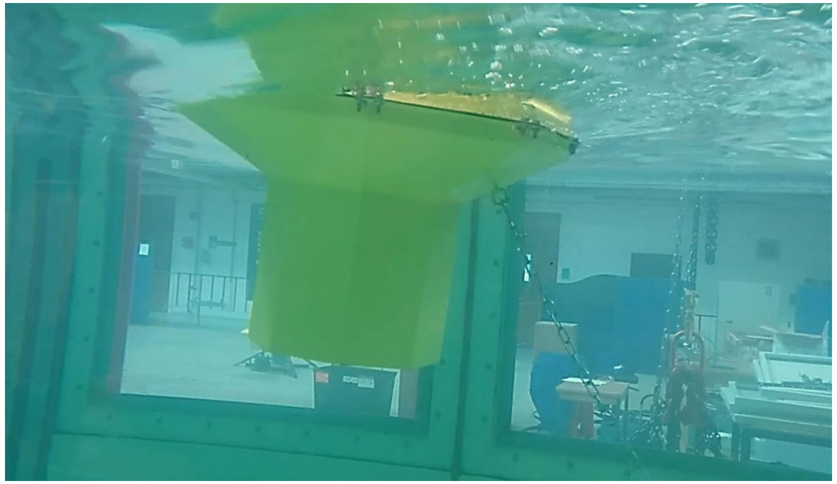
WP4 - Collaborations

- China & UK
  - Review of the levelized cost of wave energy based on techno-economic model



- UK
  - Environmental aspects
- USA
  - Bridge the gap between TALOS WEC small-scale modelling and the higher TRL required to provide cost evidence and demonstrate its commercial potential

TEAMER - US DoE - Collaboration

- TEAMER – WP1
  - "Numerical Modelling of the TALOS Wave Energy Converter"
  - NREL & Sandia NL (USA) - a TEAMER funding award to build time-domain modelling for TALOS WEC using WEC-SIM facility

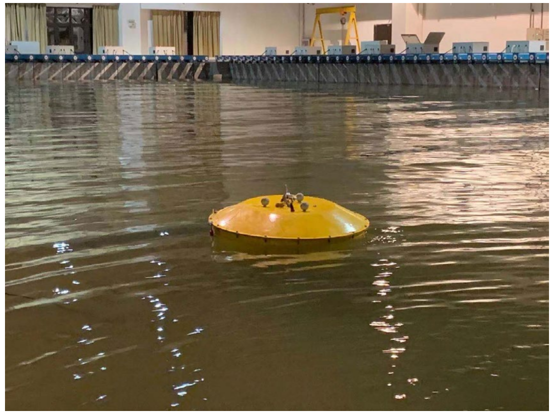
WEC-Sim

Wave Energy Converter SIMulator

- TEAMER – WP2
  - "Advanced data acquisition and fault diagnosis system for wave energy converter"
  - NREL (USA) - a TEAMER funding application

- TEAMER – WP3
  - "A test bed for the TALOS wave energy converter"
  - NREL (USA) - a TEAMER funding application

TALOS - International Collaboration



Experimental Modelling and Validation of the Computational Modelling for TALOS WEC

ISOPE 2023 - Canada

- Renewable Energy and Environment Symposium of ISOPE 2023 Ottawa, Canada, June 19–23, 2023.

- ISOPE 2023 includes a specific focus session with title: "Recent developments on TALOS WEC project".

- There are 14 TALOS related paper abstract submissions to date including:

- 2 from USA (WP1 and WP4)
- 2 from China (WP1 and WP4)
- 2 from Greece (WP1 and WP3)
- 1 from Turkey (WP2)
- 2 from the UK (both on WP2)
- 1 from US/UK Fulbright Scholar on WP2, and
- 4 from the NPH-WEC Project - 1 for WP1, 1 for WP2, 1 for WP3 and 1 for WP4.

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ISOPE 2023 – TALOS Papers

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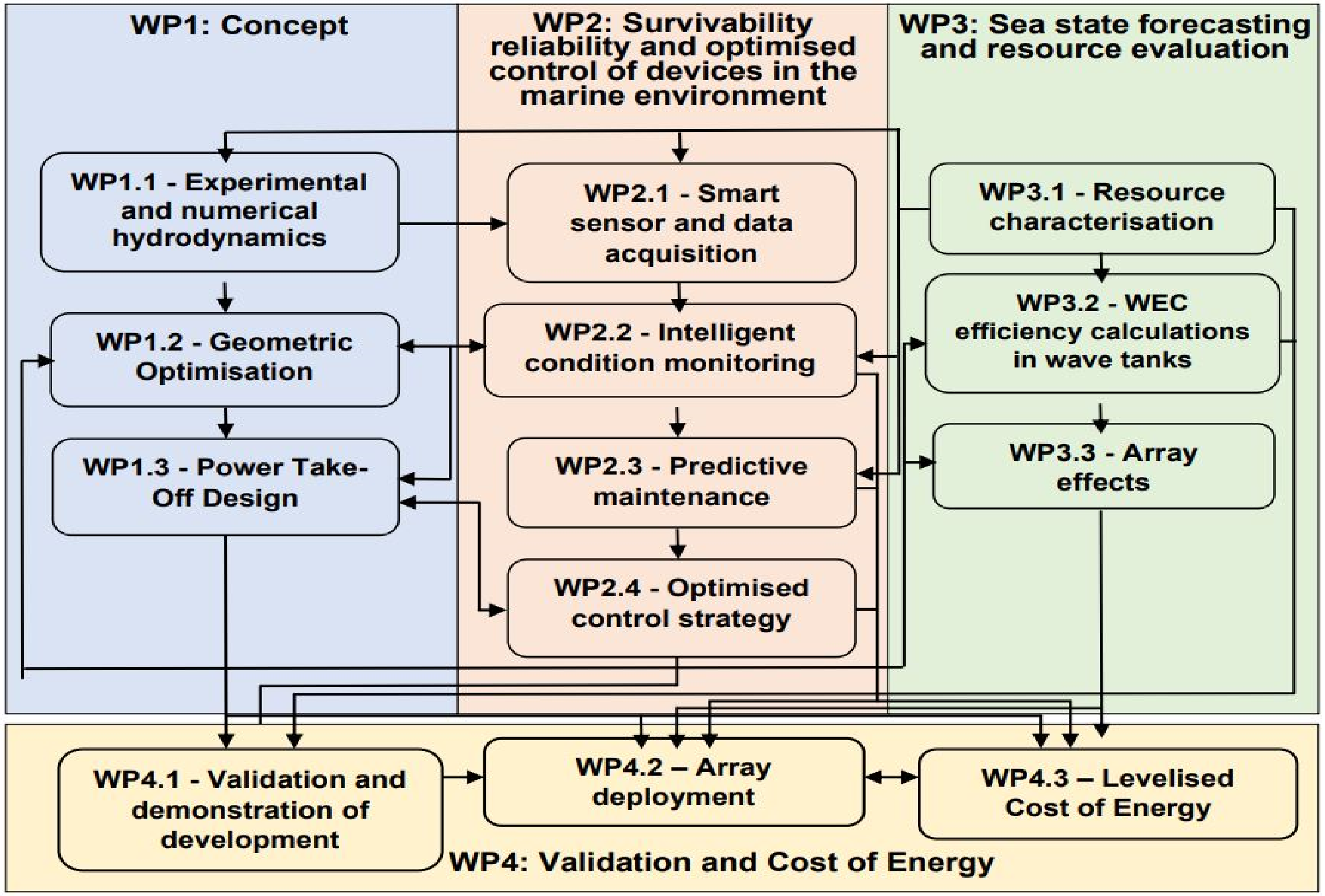
- **WP1 - NPH-WEC Project** - *Hydrodynamic studies of TALOS WEC using different open source panel methods*
- **WP2 - NPH-WEC Project** - *Machine learning based TALOS wave energy converter power output prediction*
- **WP3 - NPH-WEC Project** - *Wave power resource dynamics for the period 1980-2021 in Atlantic Europe's Northwest seas*
- **WP4 - NPH-WEC Project** - *An overview of the levelized cost of wave energy*



TALOS WP1
International Collaboration

LUREG
Lancaster University
Renewable Energy Group

Lancaster University

USA - *Time-Domain Modelling of the TALOS WEC using WEC-Sim*

USA - *Numerical Modelling of the TALOS Wave Energy Converter*

NREL Transforming ENERGY | Sandia National Laboratories | TEAMER Testing & Expertise for Marine Energy | U.S. DEPARTMENT OF ENERGY

Greece - *Time-Domain Analysis of the TALOS WEC using different computational tools*

NTUA | INTERNATIONAL HELLENIC UNIVERSITY | ARISTOTLE UNIVERSITY OF THESSALONIKI | DNV - SESAM | DNV

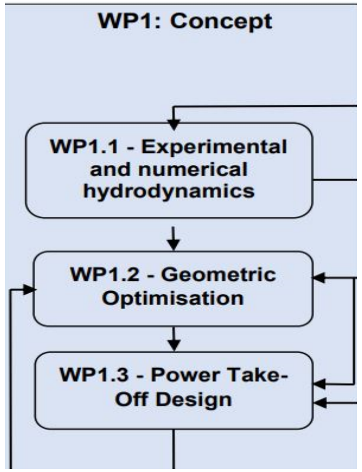
France

CENTRALE NANTES

NEMOH - Boundary Element Methods (BEM) code

China - *Numerical and experimental study on a scaled TALOS wave energy converter*

ZHEJIANG UNIVERSITY 1897



Turkey - *An initial study on power capture performance analysis of TALOS based on power take-off system parameters*

ÇUKUROVA ÜNİVERSİTESİ 1973

Taiwan

國立陽明交通大學
NATIONAL YANG MING CHIAO TUNG UNIVERSITY

Spain

SENER

UNIVERSITY OF HULL | ENERGY AND ENVIRONMENT INSTITUTE | UKRI Engineering and Physical Sciences Research Council | School of Engineering | Lancaster University

LUREG
Lancaster University Renewable Energy Group

TALOS WP2
International & National Collaboration

Lancaster University

USA - *Advanced data acquisition and fault diagnosis system for wave energy converter*

NREL Transforming ENERGY | TEAMER Testing & Expertise for Marine Energy | U.S. DEPARTMENT OF ENERGY

USA - *The Impact of Constraints on the Control of a Wave Energy Conversion with a Hydraulic PTO System*

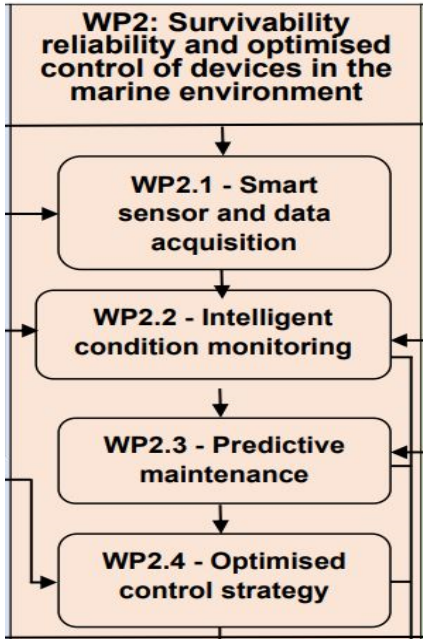
ILLINOIS TECH

UK - **Fully probabilistic control design application on TALOS wave energy converters (WEC) Array**

Edinburgh Napier University

UK - **Medium-Voltage Modular Power Converter for Wave Energy Conversion Systems**

Lancaster University



Ireland

Maynooth University National University of Ireland Maynooth

Turkey *- An initial study on power capture performance analysis of TALOS based on power take-off system parameters*

Çukurova Üniversitesi 1973

UNIVERSITY OF HULL | ENERGY AND ENVIRONMENT INSTITUTE

UKRI Engineering and Physical Sciences Research Council

School of Engineering | Lancaster University

Lancaster University Renewable Energy Group

TALOS WP3
International Collaboration

Lancaster University

USA - A test bed for the TALOS wave energy converter

NREL Transforming ENERGY · TEAMER Testing & Expertise for Marine Energy · U.S. DEPARTMENT OF ENERGY

Greece - *Time-Domain Analysis of the TALOS WEC using different computational tools*

POSEIDON SYSTEM

EU - *Time-Domain Analysis of the TALOS WEC using different computational tools*

Copernicus Europe's eyes on Earth · Copernicus Marine Service

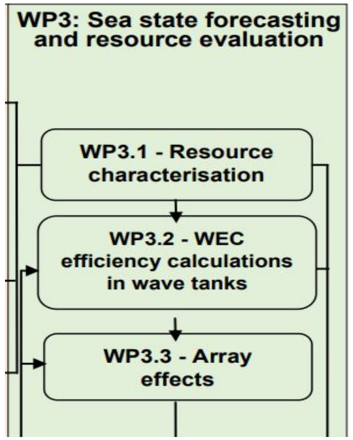
EC

European Commission

Joint Research Centre

Canada

University of Victoria



TALOS WP4
International Collaboration

USA - **Characterizing the use of Wireless Communication for Subsea Data Transmission**

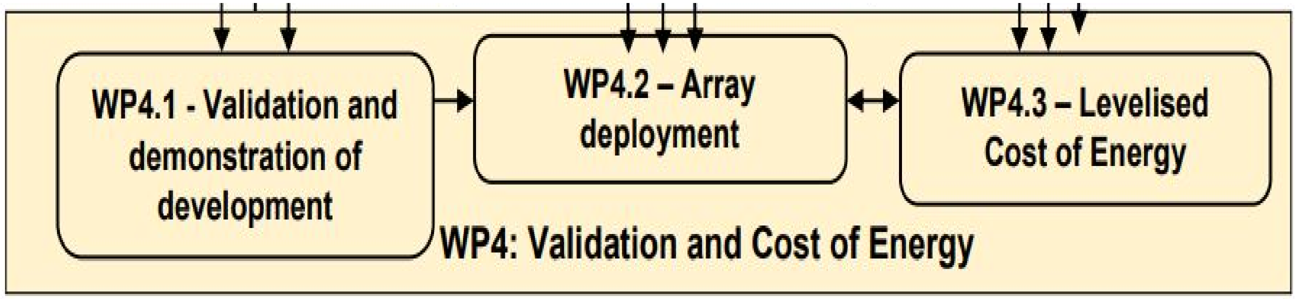
USA

- **Evaluating long-term investments in emerging energy technologies in the United Kingdom with TALOS WEC as a case study**
- **Bridge the gap between TALOS WEC small-scale modelling and the higher TRL required to provide cost evidence and demonstrate its commercial potential**

Malibu
California
USA

China - **A Method of Obtaining Biological Inspiration to Improve the Performance of TALOS WEC**

Canada



LUREG
Lancaster University
Renewable Energy Group

Lancaster University

TALOS WEC
VIDEO
taken during
Experimental Modelling
at the Wave Basin Testing facility
of Zhejiang University in China

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UKRI Engineering and Physical Sciences Research Council

School of Engineering | Lancaster University

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FIMechE, FIMarEST, FEI, FIET

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Thank you

WE LOOK FORWARD TO HEARING FROM YOU.

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