Title: A Techno-Economic GIS for Ocean Energy

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INTRO

There are many GIS and TE tools geared for renewable energy applications. However:

- Few are suitable for wave and tidal energy applications
- Those available either adopt a GIS or a TE approach, not a combination
- They are limited by lack of up-to-date, high-resolution information on specific sites
- Full TE functionality is not open-access

For WP4 of the Selkie Project, I have designed and developed a fully open-access GIS Techno-Economic (GIS-TE) tool, suitable for wave and tidal energy project developers, academia and government. The tool can:

- Propose sites and produce techno-economic recommendations for wave and tidal energy technologies in Irish and UK waters.
    - The GIS aspect allows for identification of potential sites
    - The TE element facilitates assessment of project feasibility at these sites

METHODS

1. The web-interface was developed in HTML, CSS and JavaScript with the help of Esri Developer's JavaScript API.
2. The GIS data was gathered from a range of open access sources across Ireland and the UK to depict all relevant constraints, restrictions and opportunities.
3. The wave and tidal resource data also came from open access sources and is of an unprecedented spatial resolution for any tool of its kind (~1.5km both for wave and tidal). Using MATLAB code, wave data was tested against in-situ data for accuracy, but this was not possible for tidal data due to lack of validation sources.
4. Default techno-economic inputs in the tool are either geospatially determined by where the user clicks on the map (i.e. distance inputs) or are derived from the available literature (i.e. cost inputs). Annual Energy Production (AEP) was calculated by applying the resource data to power matrices/curves in MATLAB.

LCOE is inherently spatial in nature, thus the location of a project has a resounding effect on the output. Combining GIS with Techno-Economics can address this.

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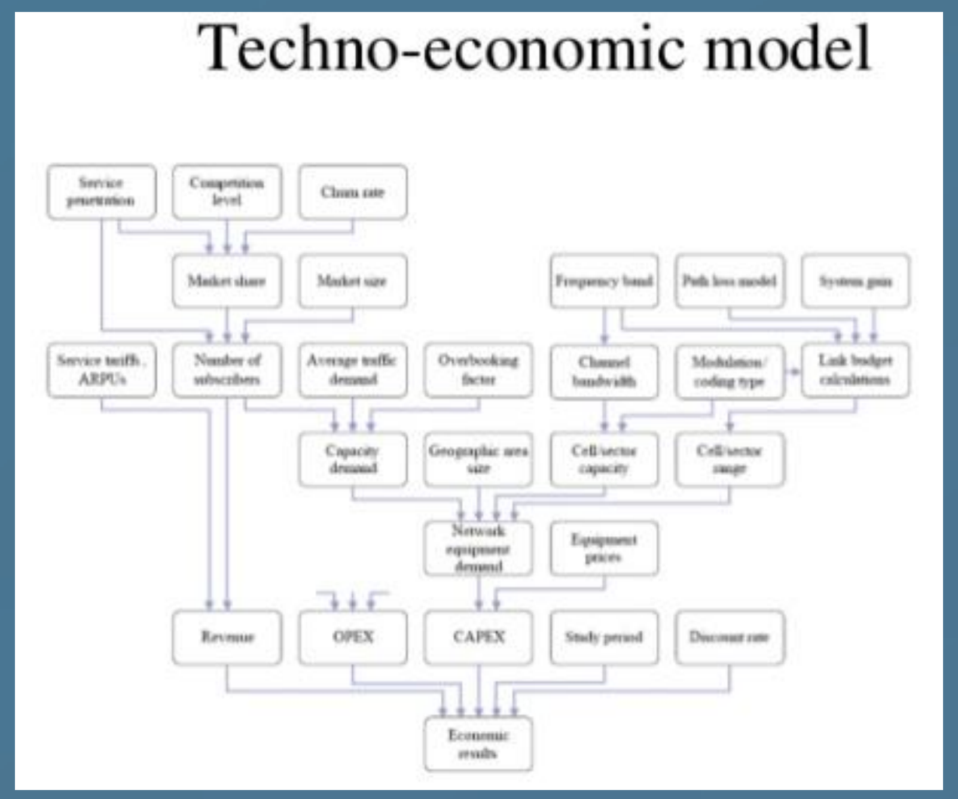
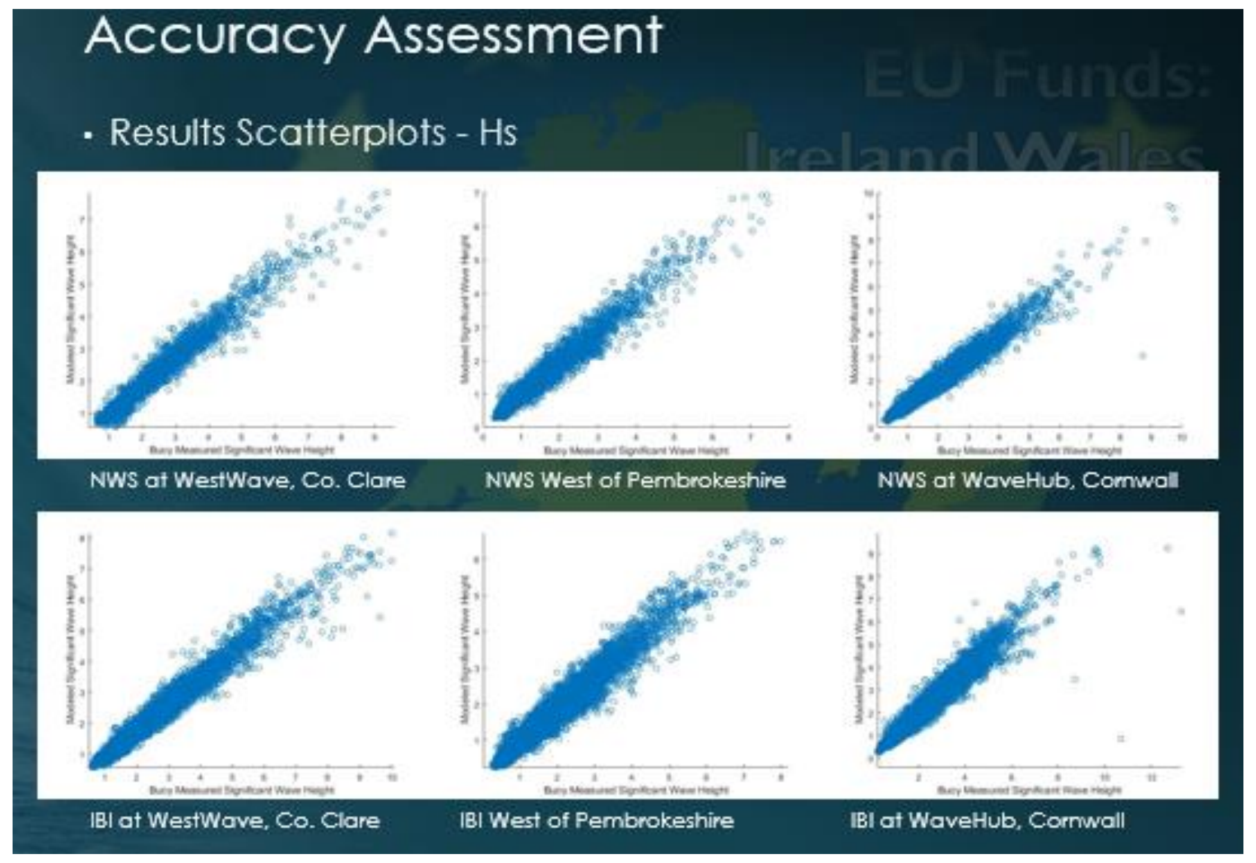

Techno-economic model

= LCOE

HOST INSTITUTION
PARTNER INSTITUTIONS
FUNDED BY:

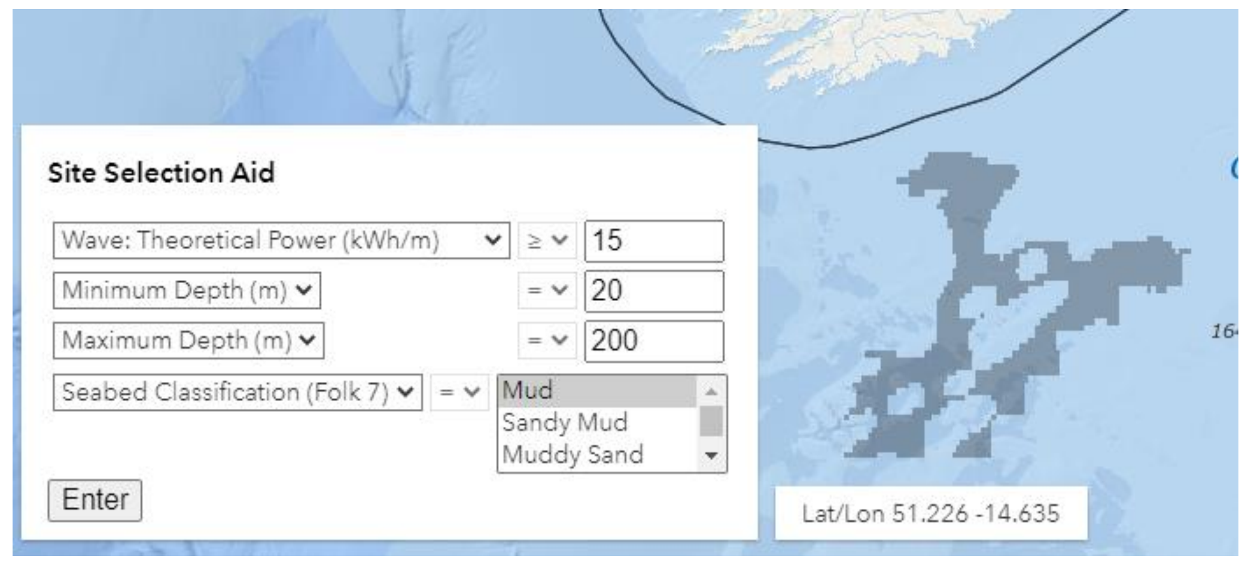

Accuracy Assessment

- Results Scatterplots - Hs

NWS at WestWave, Co. Clare
NWS West of Pembrokeshire
NWS at WaveHub, Cornwall
IBI at WestWave, Co. Clare
IBI West of Pembrokeshire
IBI at WaveHub, Cornwall

RESULTS

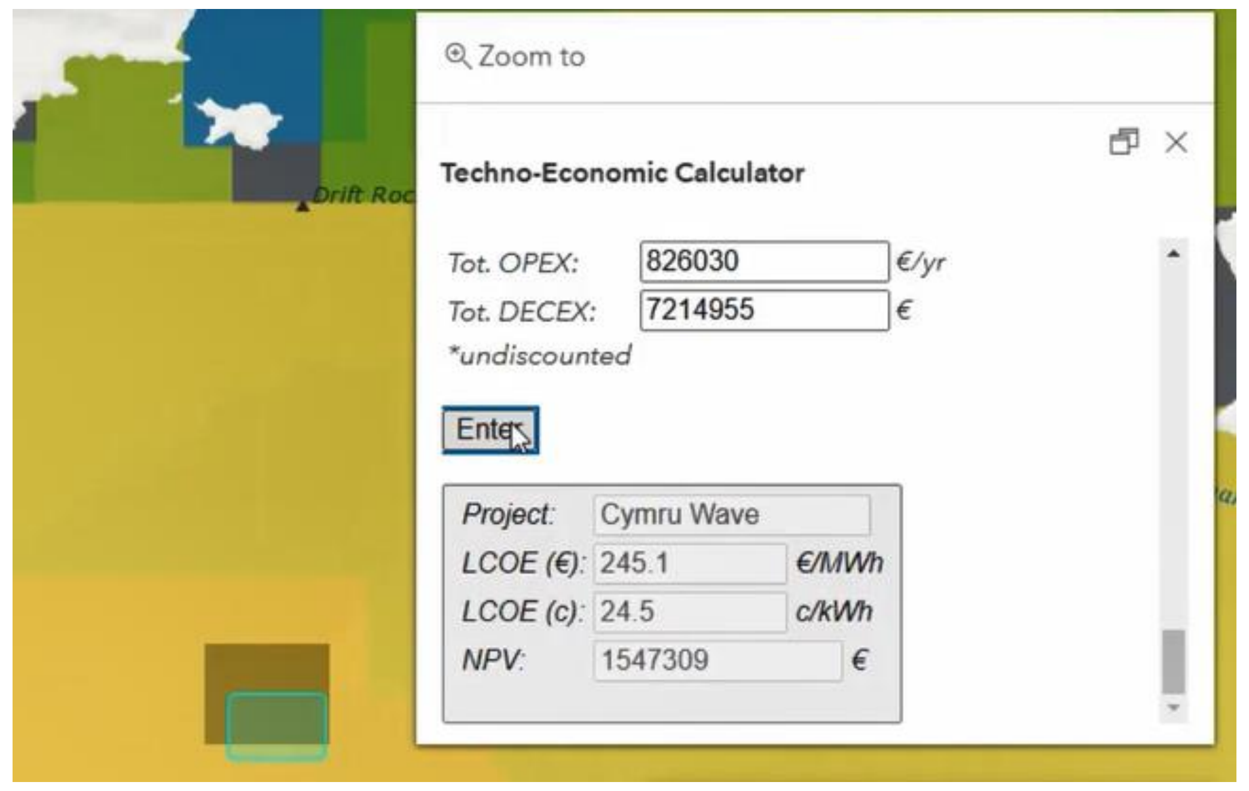
- Good correlation between model data and in-situ validation data for wave height and period (above).
- Using real case study scenarios based on industry survey responses, the Site-Selection Aid (within the tool) reveals several locations meeting desired criteria to show suitable sites (below).


Site Selection Aid

Wave: Theoretical Power (kWh/m) ≥ 15
Minimum Depth (m) = 20
Maximum Depth (m) = 200
Seabed Classification (Folk 7) = Mud
Sandy Mud
Muddy Sand

Lat/Lon 51.226 -14.635

- Running the Techno-Economic model on some of these sites to assess project feasibility KPIs reveals LCOE returns of as low as 24.5 c/kWh (below). However, these results vary drastically depending on the site location (i.e. where the map is clicked).


Techno-Economic Calculator

Tot. OPEX: 826030 €/yr
Tot. DECEX: 7214955 €
*undiscounted

Project: Cymru Wave
LCOE (€): 245.1 €/MWh
LCOE (c): 24.5 c/kWh
NPV: 1547309 €

Conclusion

- Open-source GIS data from across the web can be integrated to decision making tools such as this to enable effective site suitability assessment for wave and tidal energy farm deployments.
- Open-access oceanographic models with a high spatial resolution that have recently become available online perform well when assessed for accuracy against in-situ validation points and can be used to get the AEP of ocean energy devices when applied to the device technical data.
- KPIs such as LCOE are inherently spatial in nature, and thus the location of a project has a resounding impact on said.

Bionic Adaptive Stretchable Materials for Wave Energy Converters (BASM-WEC)

EPSRC Marine Wave Energy Call 2021: EP/V040553/1

Project Investigators: Qing Xiao, Sandy Day, Feargal Brennan, Liu Yang, Iain Bomphray
Researchers: Farhad Abad, Guillermo Idarraga Alarcon, Yang Huang, Saishuai Dai, Saeid Lotfian

University of Strathclyde Engineering

Introduction

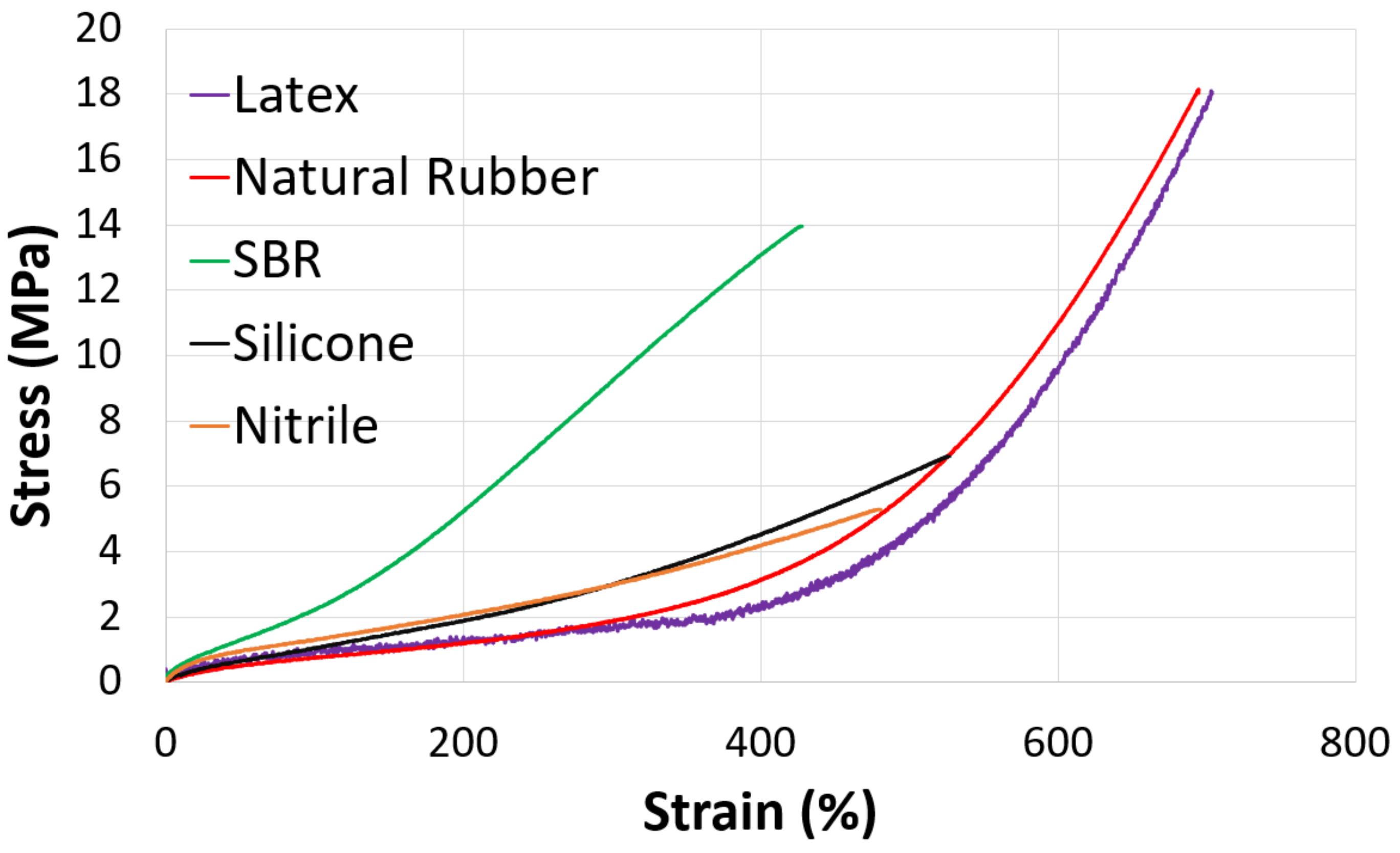
Wave Energy Converters (WECs) transform the kinetic and/or potential energy of ocean waves into electricity. Among different types of WECs technologies, none of them achieves economic competitiveness. The main challenges of commercialisation of existing WECs arise from the devices' low-performance efficiency and the WEC system's vulnerability under harsh sea conditions.

Aim

To develop an analysis and laboratory testing integrity toolbox to reliably design, analyse, and process the state of the art adaptive stretchable materials and structures applicable to WECs.

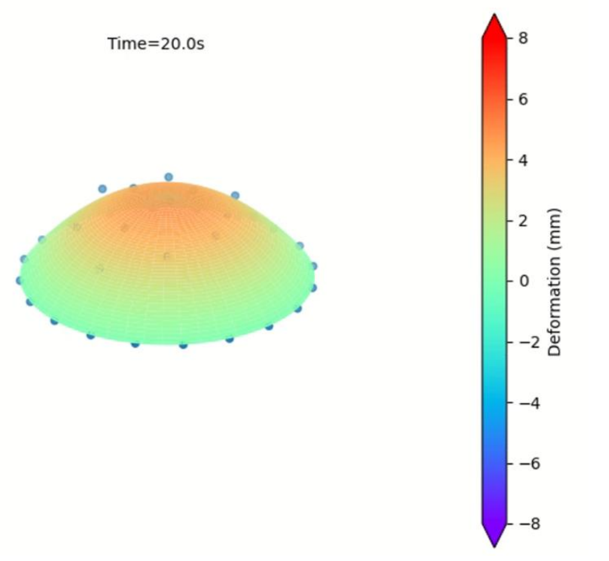
Flexible Materials in WECs

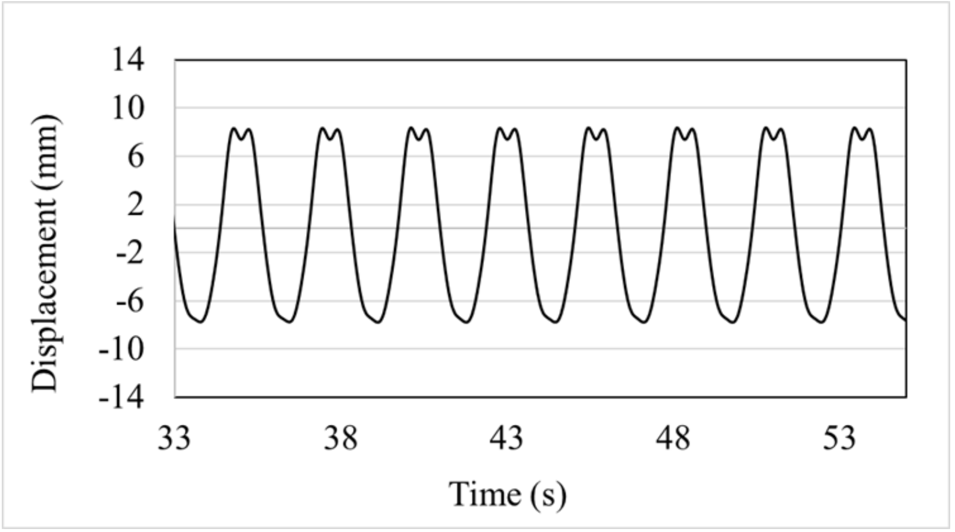
Elastomers have high elongation, damping coefficient and fatigue life but low strength and low stiffness.

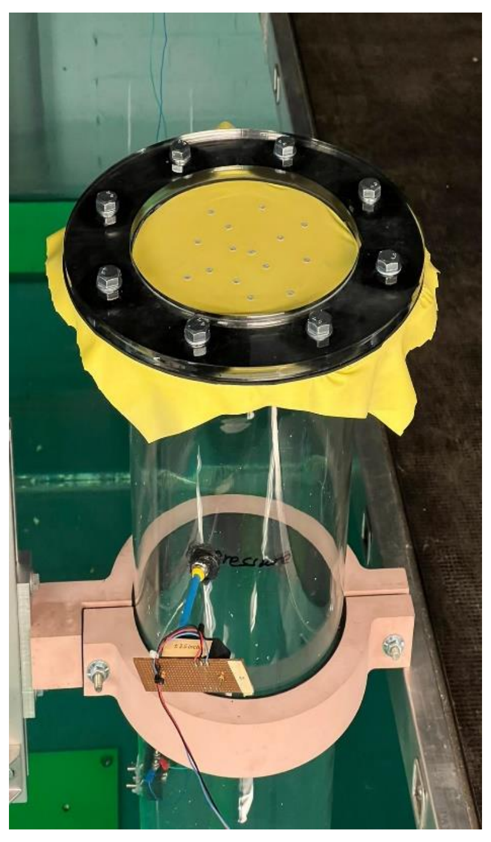


Oscillating Water Column (OWC)

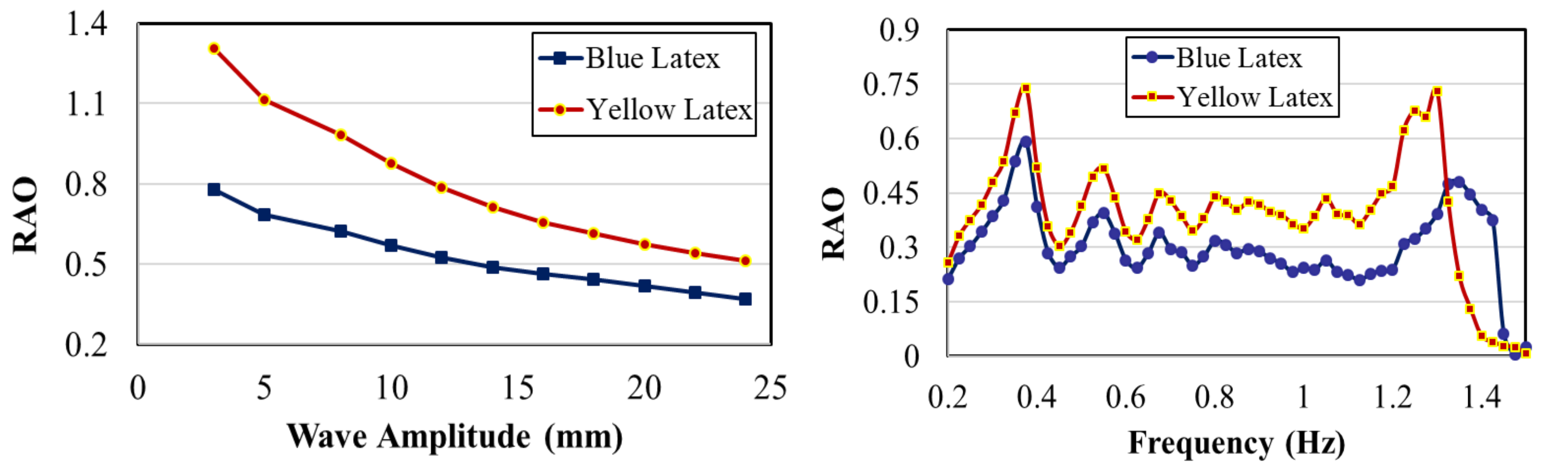
In order to see the behaviour of the material in the actual wave condition, several tests on a small scale OWC with flexible material at its top have been done in a wave tank.





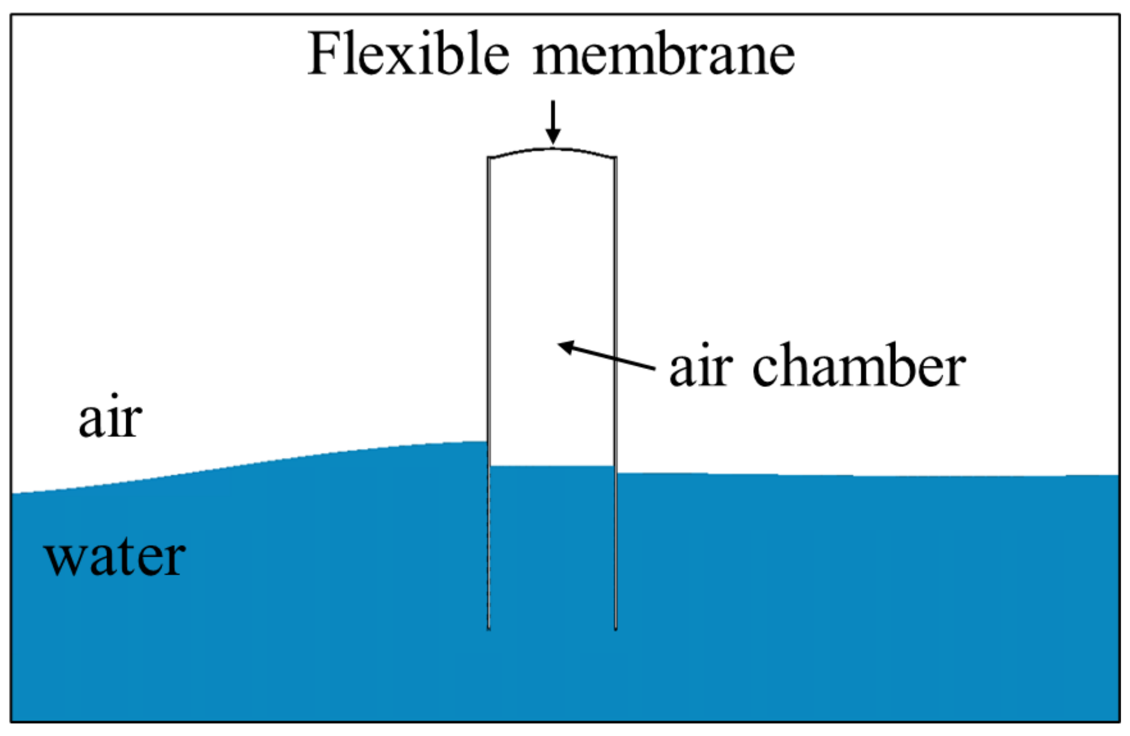


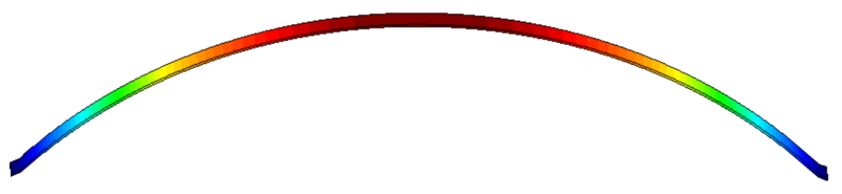
Study on non-dimensional analysis and scaling are another purpose of these tests. Here are the RAO of oscillating water surface elevation with two different elastomers vs. wave amplitude & frequency.



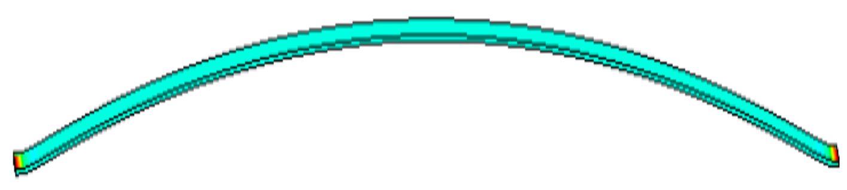
CFD Numerical Simulation

A hydro-elastic analysis tool based on advanced CFD techniques is developed to provide a robust analysis method for various flexible WECs. Flow details around the flexible WECs and dynamic responses of the flexible structure are predicted using a strong coupling way.

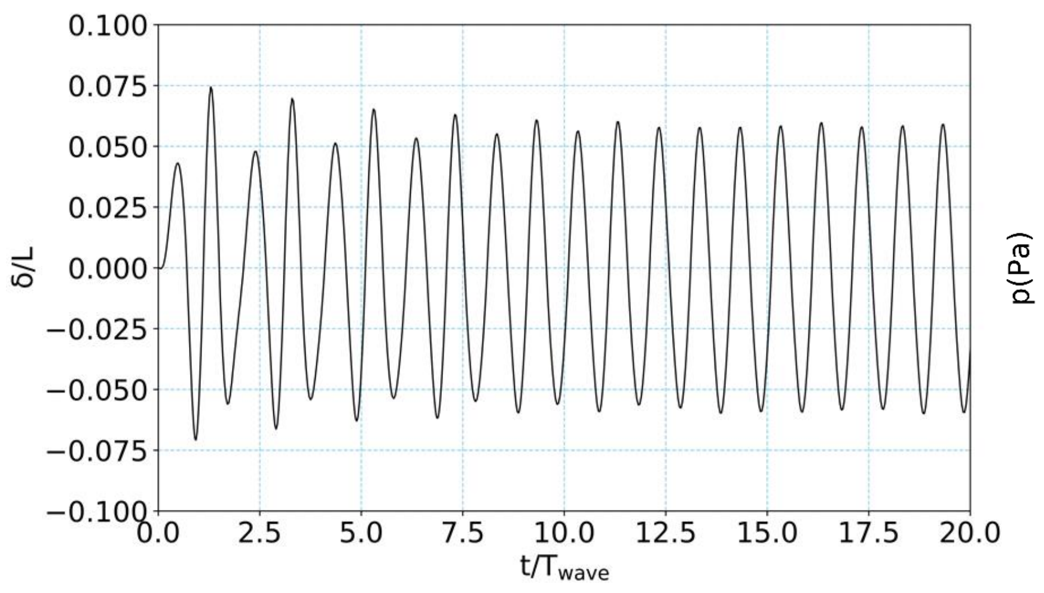




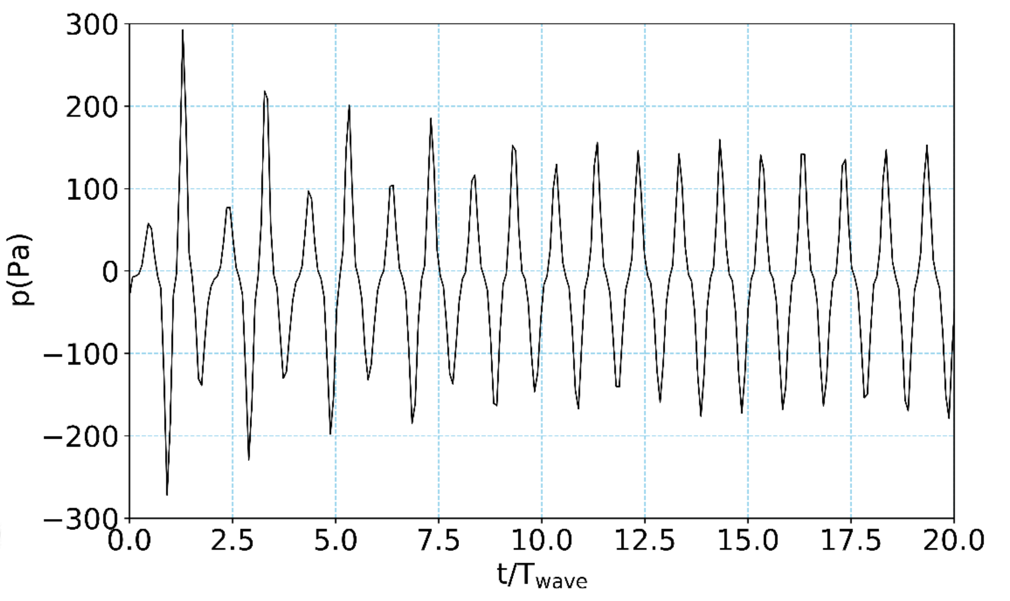
Structural deformation



Stress distribution



Time history of displacement



Time history of pressure in air chamber

Future work

Here are some desirable actions for future work:

- Designing and building up a new test rig to test more flexible materials and adding a power take-off such as DEGs to the system.
- Performing bi-axial and planar tests to complete material characterisation, and material modification.
- Conducting CFD numerical analysis for WECs.

HAPiWEC

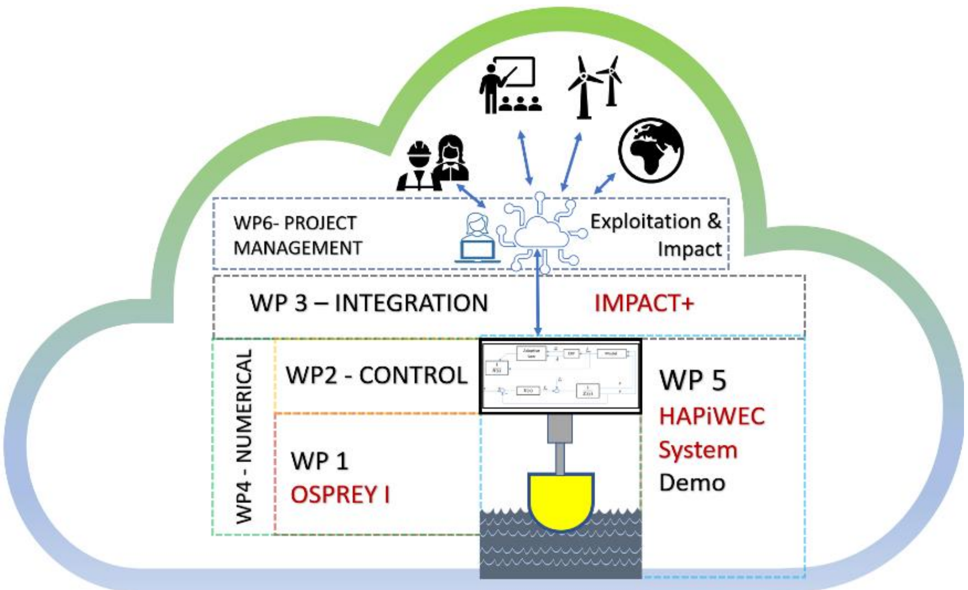
MULTI-USER
REMOTELY ACCESSIBLE
PROOF OF CONCEPT DEMONSTRATOR

Holistic Advanced Prototyping and Interfacing for Wave Energy Control

Prof. Bill Leithead, Dr. Adam Stock, Dr David Campos Gaona (University of Strathclyde)
Dr. Brian Sellar, Dr. David Forehand, Dr. Thomas Davey, Prof. Alasdair McDonald (University of Edinburgh)`

MULTI-USER
REMOTELY ACCESSIBLE
PROOF OF CONCEPT DEMONSTRATOR

> “This project proposes that through the implementation of rapid prototyping hardware and remotely accessible user control, novel control algorithms can be demonstrated and validated at unprecedented levels of efficiency”



WP6- PROJECT MANAGEMENT

Exploitation & Impact

WP 3 – INTEGRATION

IMPACT+

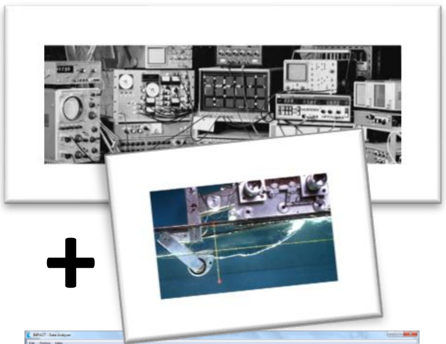
WP4 - NUMERICAL

WP2 - CONTROL

WP 1
OSPREY I

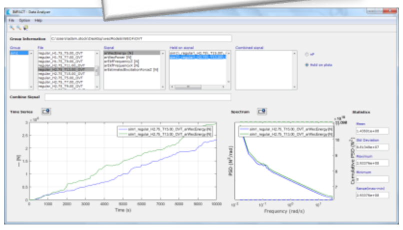
WP 5
HAPiWEC
System
Demo

WP1
The Osprey-I Test Rig



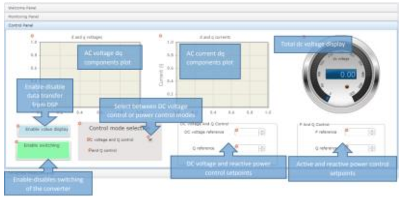
Remove barriers to availability of WEC models for testing novel control ideas.

WP2
Optimal Velocity Tracking Control for WECS



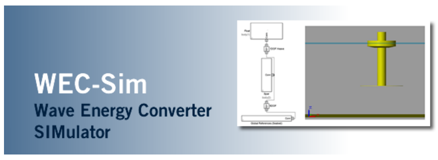
Develop impedance matching control and apply to freely available IMPACT+ toolbox.

WP3
Rapid Prototyping to Enable Controllable WECs



Modular based approach with graphical user interface for remote deployment.

WP4
Numerical Modelling



Link Osprey I (WP1) and OVT (WP2) to assess control strategies prior to tank testing.

WP5 & WP6
Tank Testing and Remote Access

Deploy Osprey I in FloWave with remote access for the control community.

University of Strathclyde Engineering

THE UNIVERSITY of EDINBURGH

NREL Transforming ENERGY

CENTRALE NANTES

WEAMEC MARINE ENERGY

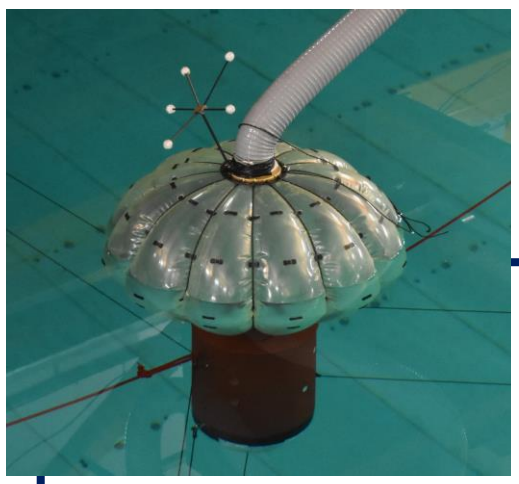
RENEWABLE DYNAMICS

wave energy SCOTLAND

Flexible Responsive Systems in Wave Energy: FlexWave

Jingyi Yang[2], Martyn Hann[1], Zhong You[2], John R Chaplin[3], Alistair Borthwick[1], Robert Rawlinson-Smith[1],
Shanshan Cheng[1], Maozhou Meng[1], Edward Ransley[1], Siming Zheng[1],
Xinyu Wang[1], Krishnendu Puzhukkil[1], Deborah Greaves[1*]

[1] **University of Plymouth,** [2] **University of Oxford,** [3] **University of Southampton**



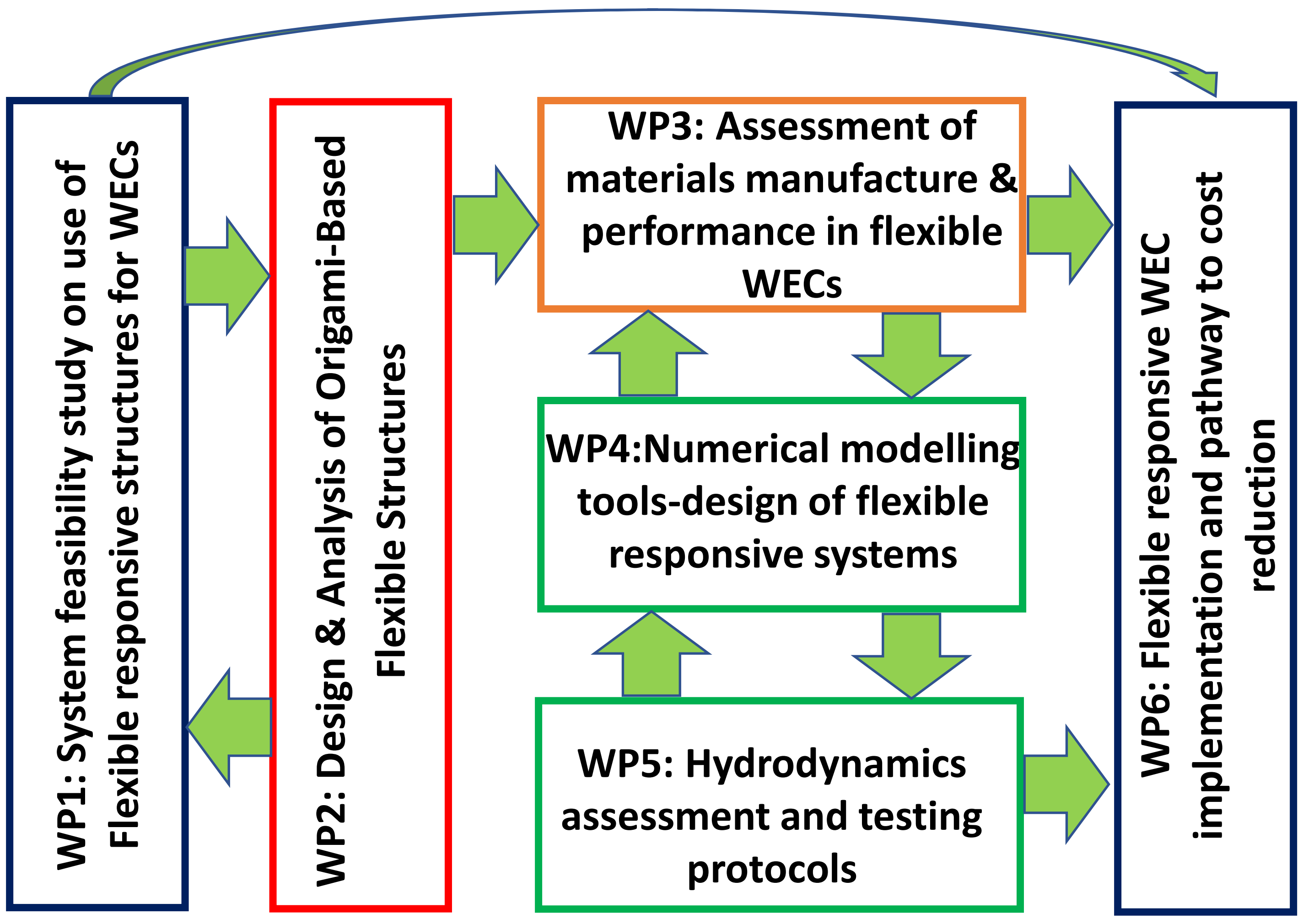
AIM

- Step change reduction in cost of energy
- Niche application wave energy converter (WEC) designs through the use of Flexible Responsive Systems in Wave Energy
- Shape-changing flexible structures - inelastic folding and elastic stretching

Potential WEC Configurations & PTO

- Clam WEC
- Distensible tube
- SQ
- Dielectric elastomer generator
- Pneumatic rams
- Air-turbine generator

WORK PROGRAMME (August 2021-2024)



WP1: System feasibility study on use of Flexible responsive structures for WECs

WP2: Design & Analysis of Origami-Based Flexible Structures

WP3: Assessment of materials manufacture & performance in flexible WECs

WP4:Numerical modelling tools-design of flexible responsive systems

WP5: Hydrodynamics assessment and testing protocols

WP6: Flexible responsive WEC implementation and pathway to cost reduction

Origami-based flexible structures

- Folding a flat sheet according to Fig 1 and welding along the red lines, the model in Fig 2 has been obtained
- Using a combination of rigid (yellow cardboard, Fig 2) and elastic (blue membrane) facets, we achieve predictable, localised tension in the elastic membranes when the deployable structure is in motion
- Energy loss due to material deformation is minimised, deformation and failure modes are more predictable

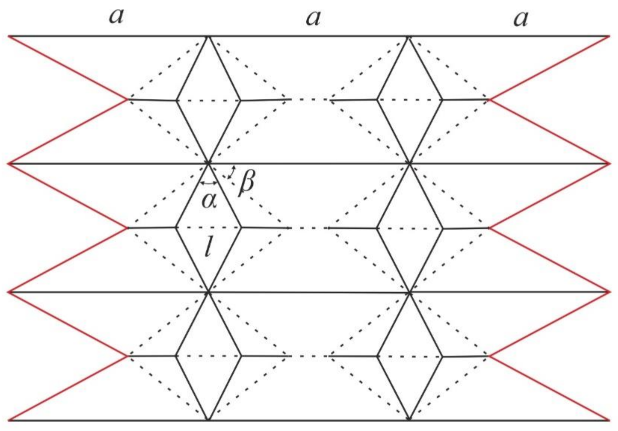
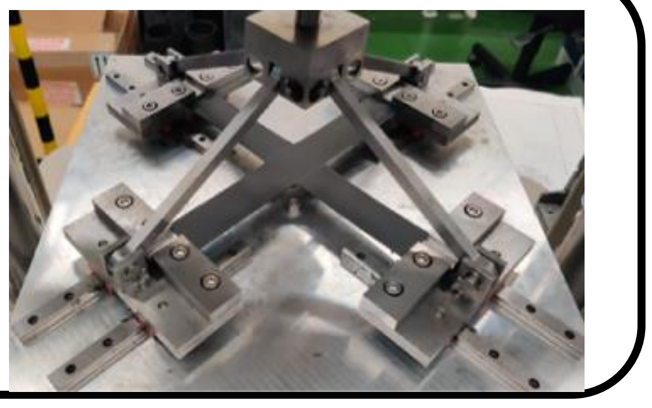


Fig 1. The crease pattern. Solid and dash lines are mountain and valley creases, respectively.

Fig 2. The prototype

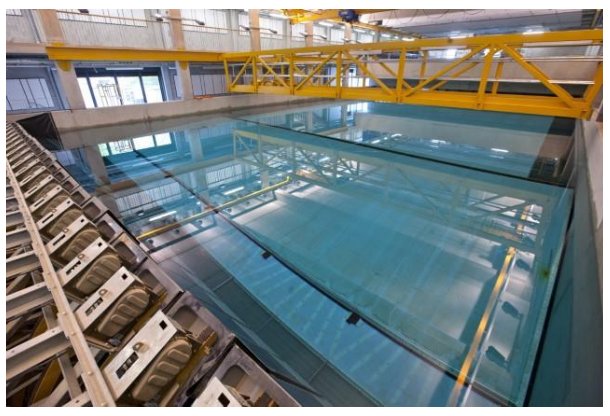
Assessment of materials

- Different flexible material & manufacturing processes will be explored to find the best material solution in terms of cost and performance
- A dynamic fatigue test to mimic behavior in irregular waves will provide insight into the lifetime performance of different materials



Hydrodynamic assessment of flexible structures

- Numerical modelling: FE Analysis (Ansys FEA)+Frequency domain analysis (WAMIT/FlexWEC)
- Hydro-elastic interaction of flexible membranes (Polyurethane, Neoprene rubber (NR) & Reinforced NR) & flexible WEC – COAST Lab, University of Plymouth
- Measurements- Strain: Flexible strain sensors; Displacement: Qualisys motion tracker system & Laser sensor



Next Steps

- Developing and optimising the crease pattern for clam concept
- Material fatigue testing in the marine environment
- Preliminary investigation on the hydro-elastic interaction of flexible membranes

Contact Email: jingyi.yang@eng.ox.ac.uk, xinyu.wang-41@plymouth.ac.uk, krishnendu.puzhukkil@plymouth.ac.uk

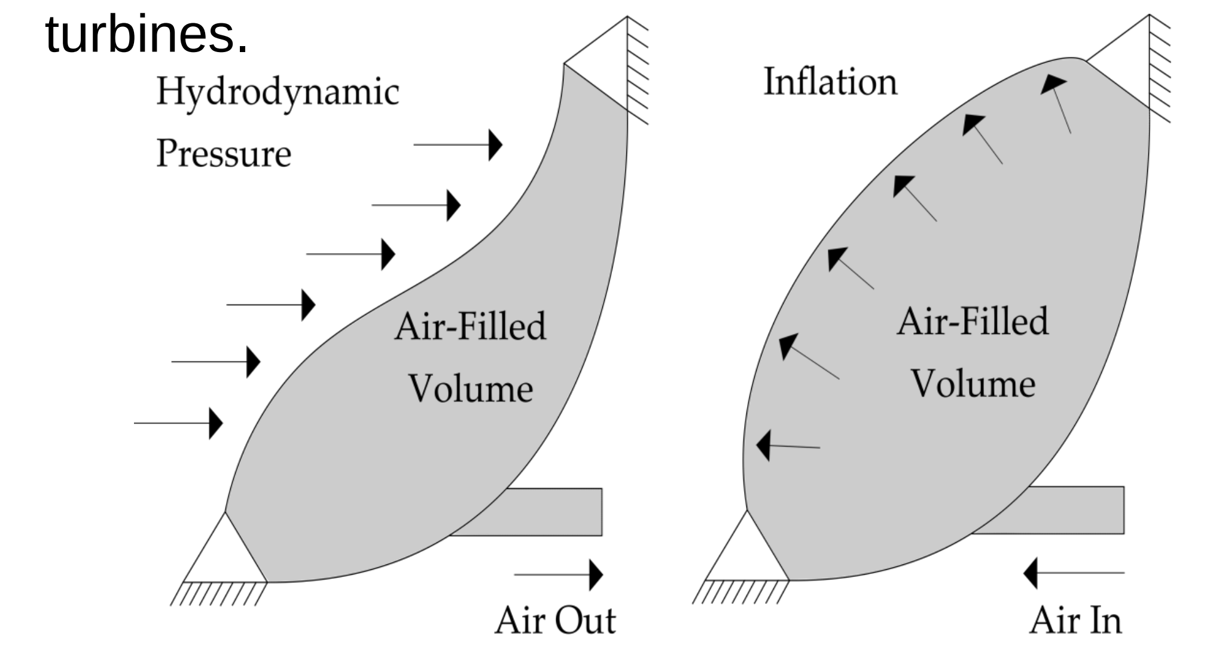
Biaxial Fatigue Characterization of Natural Rubbers filled with Carbon Nanotubes (CNTs) for Flexible Wave Energy Converters

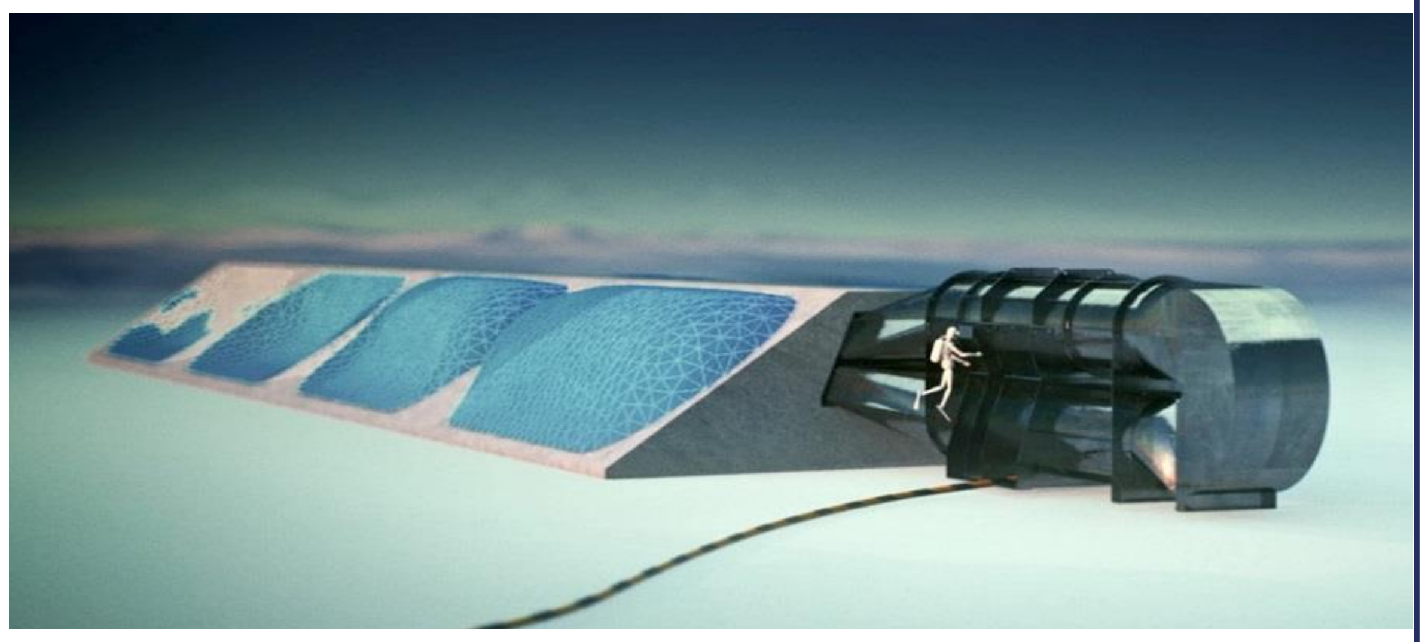
A. Esmaeili, M. Hossain and I. Masters

WES Annual Conference 2022, May 3rd, National Museum of Scotland

Applications

- Polymeric materials are used in flexible membrane-based Wave Energy Converters (mWECs).
- Inflation-deflation of the membrane originated from wave motions causes energy harvesting via air turbines.

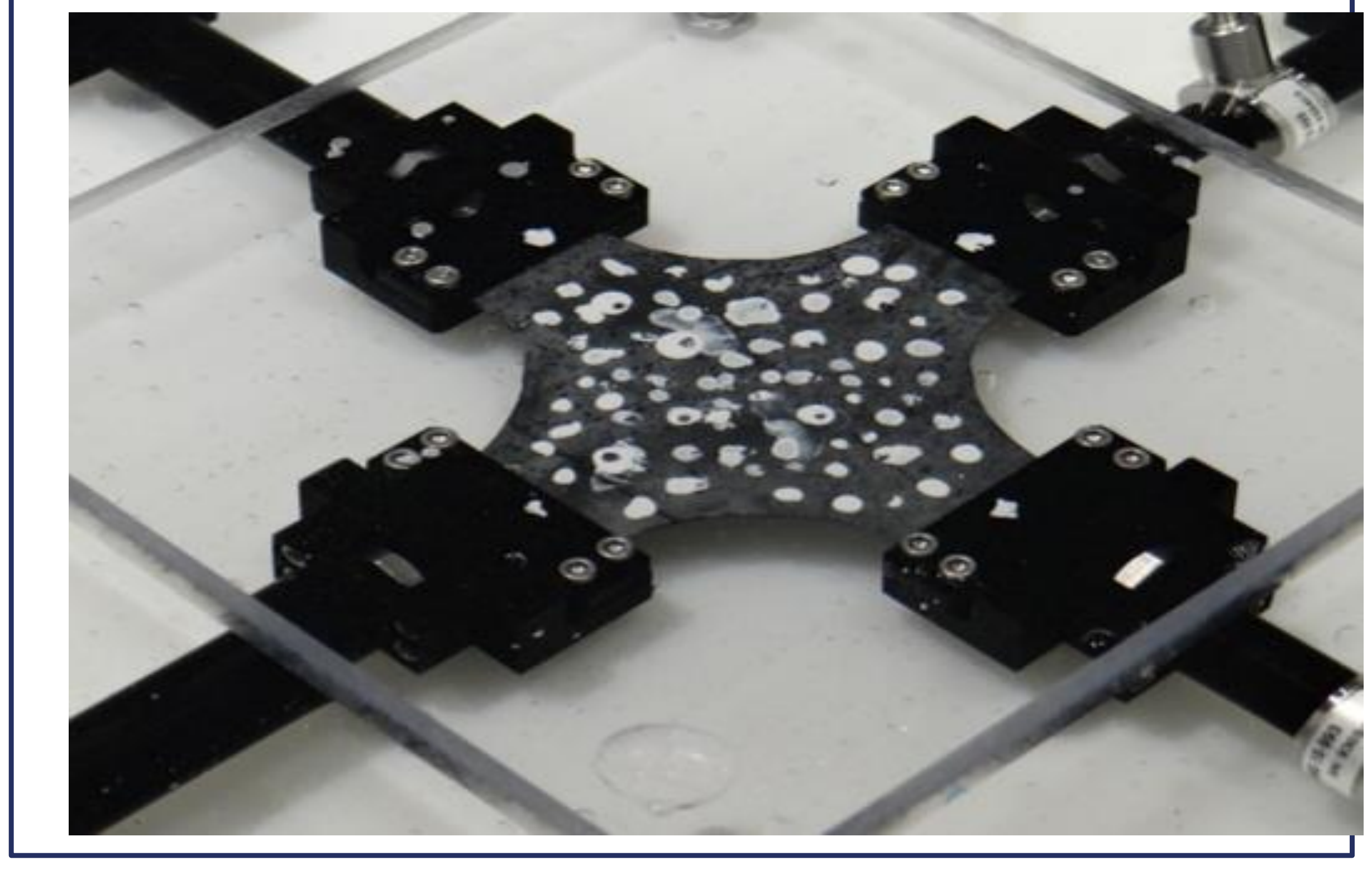




Bombora Wave Power | Ocean Energy, *2019*

Novelty & Purpose

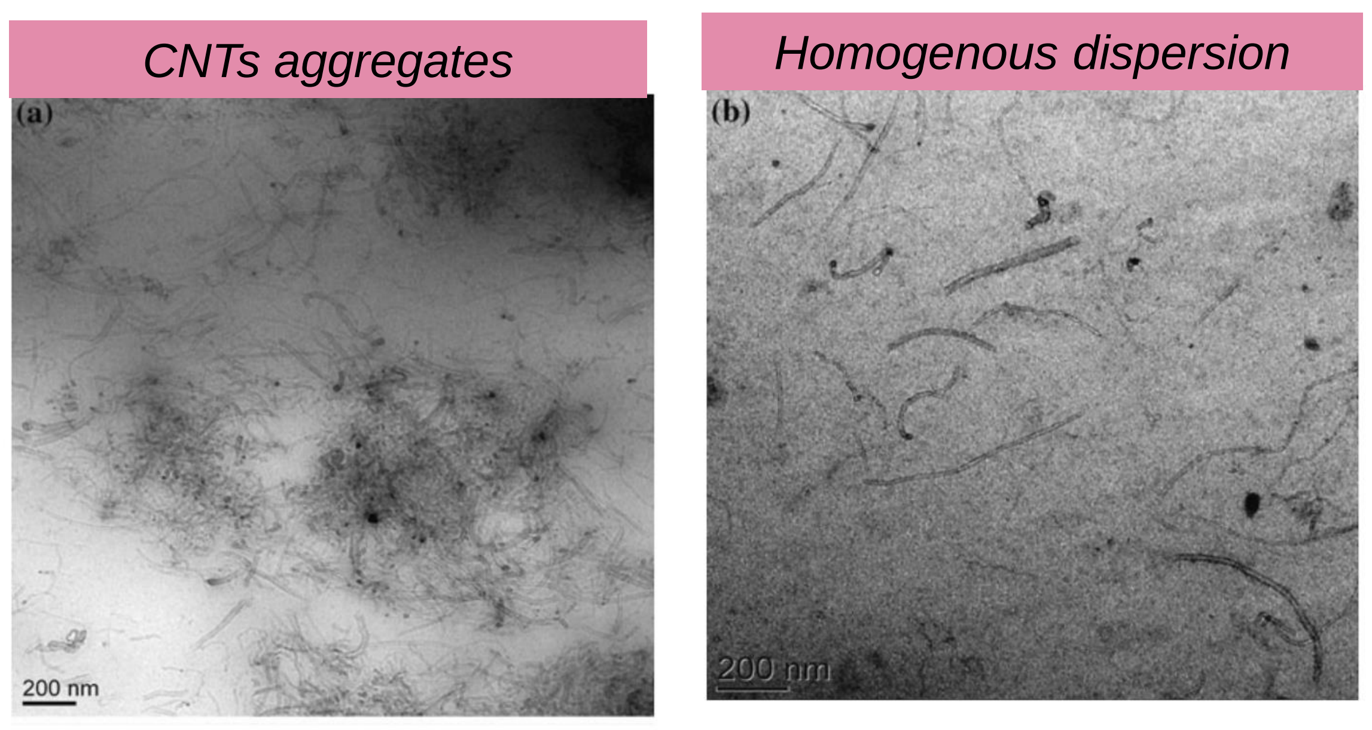
- Polymers are typically subjected to complex loading conditions.
- Flexible membranes need novel elastomeric materials with high fatigue life and low maintenance cost .
- Current fatigue tests in the literature are mostly performed in uniaxial mode with 'dry' conditions.
- To synthesize CNT/Natural Rubbers(NRs) to achieve proper mechanical properties, e.g., **ultra-low dissipative energy behaviour** and **high fatigue life.**
- To conduct biaxial fatigue experiments in submerged conditions mimicking sub-sea environments.



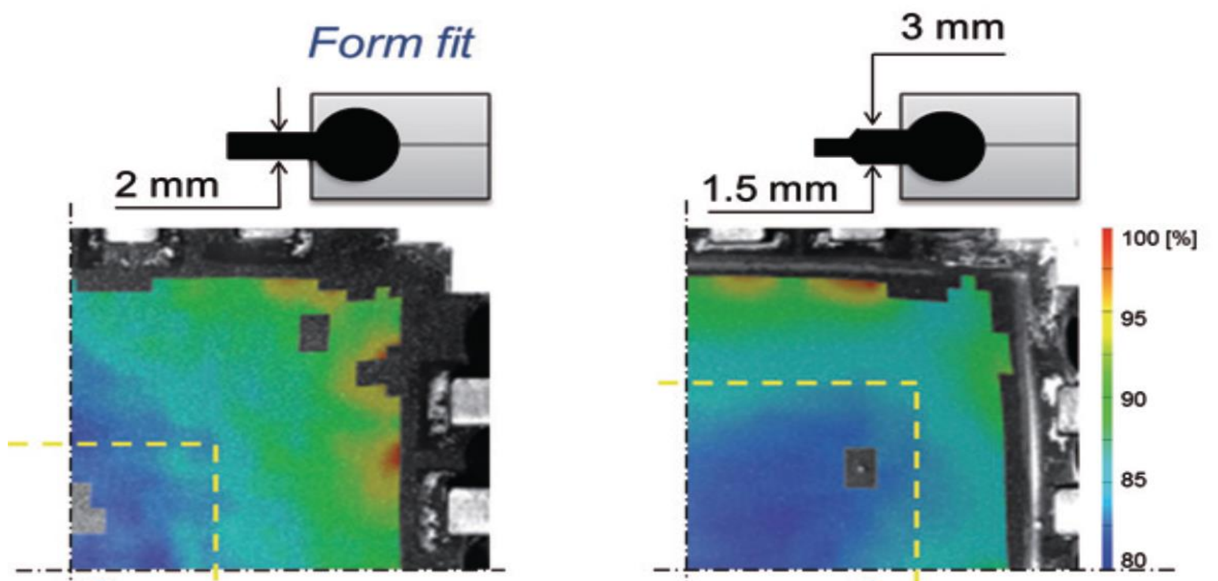
Challenges

- Agglomerations of CNTs

Thomas et al. 2012, J. Mater. Sci.

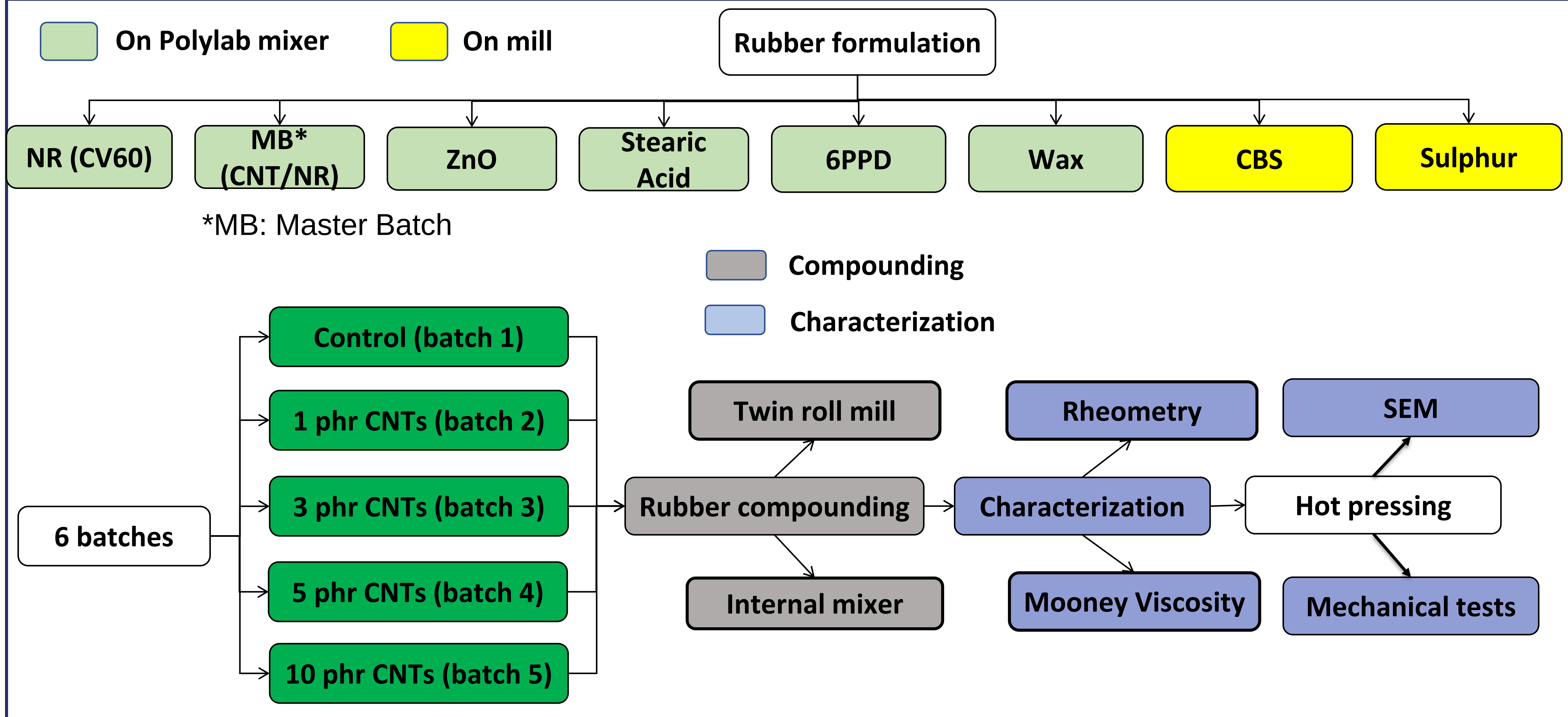


- Proper gripping of biaxial samples in fatigue test



Dedova et al. 2018, TESTING AND MEASURING

Materials and Methodology



🟩 **On Polylab mixer** 🟨 **On mill**

Rubber formulation

- **NR (CV60)**
- **MB* (CNT/NR)**
- **ZnO**
- **Stearic Acid**
- **6PPD**
- **Wax**
- **CBS**
- **Sulphur**

*MB: Master Batch

▨ **Compounding**
▨ **Characterization**

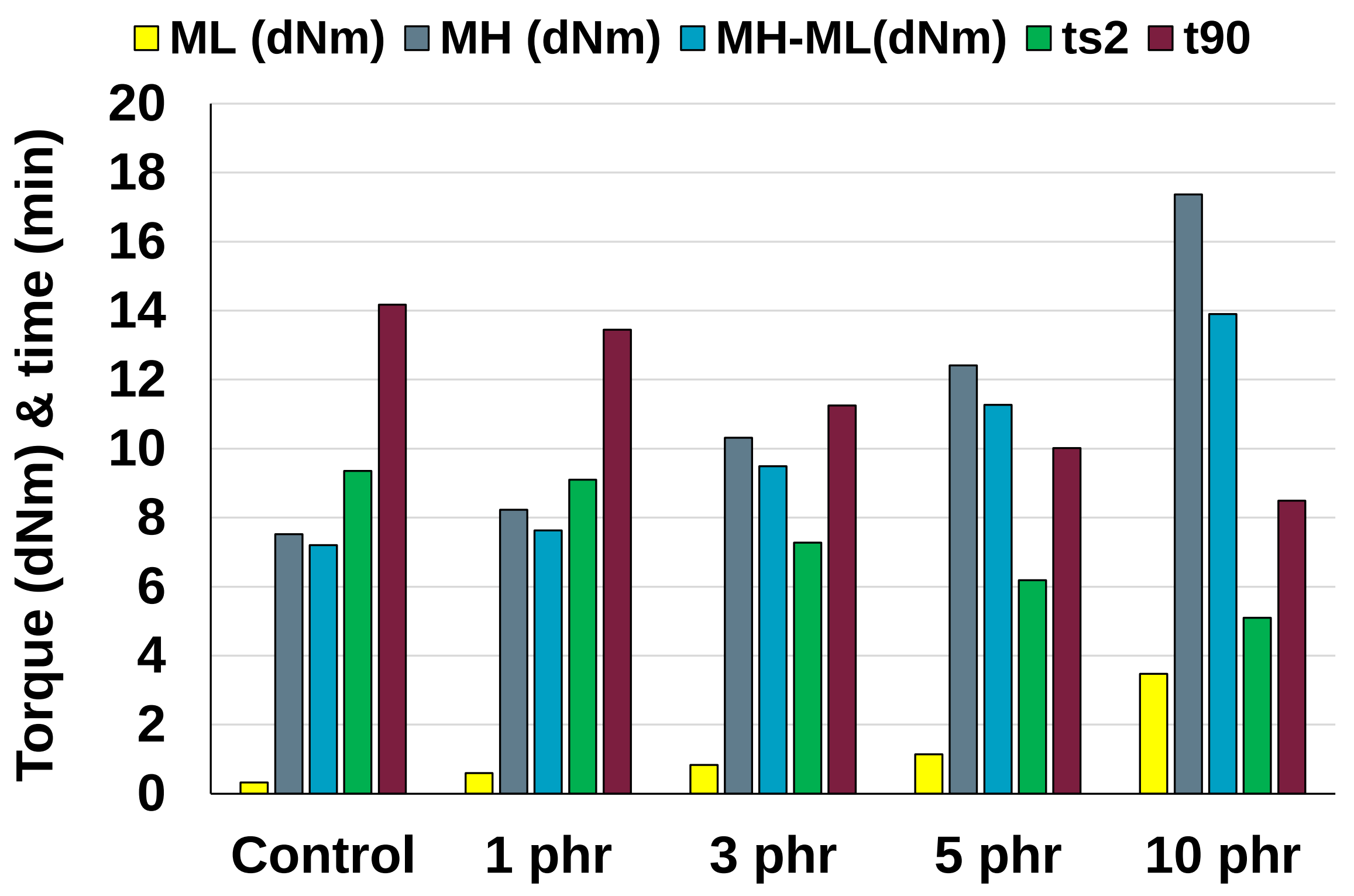
6 batches
- **Control (batch 1)**
- **1 phr CNTs (batch 2)**
- **3 phr CNTs (batch 3)**
- **5 phr CNTs (batch 4)**
- **10 phr CNTs (batch 5)**

Rubber compounding (**Twin roll mill**, **Internal mixer**) → **Characterization** (**Rheometry**, **Mooney Viscosity**) → **Hot pressing** (**SEM**, **Mechanical tests**)

(1) CV60 (2) Dissolving CV60 into toluene for 3 days (3) Mechanically dispersing sonicated CNT/toluene solution into NR/toluene solution (4) Drying NR/CNTs solution in a tray (5) Dried MB (CNT/NR) (6) homogenization of MB using twin-roll mill (7) Final MB (8) Addition of ingredients in the internal mixer (9) Adding Sulphur and CBS on twin-roll mill (10) Final uncured CNT/NR compound

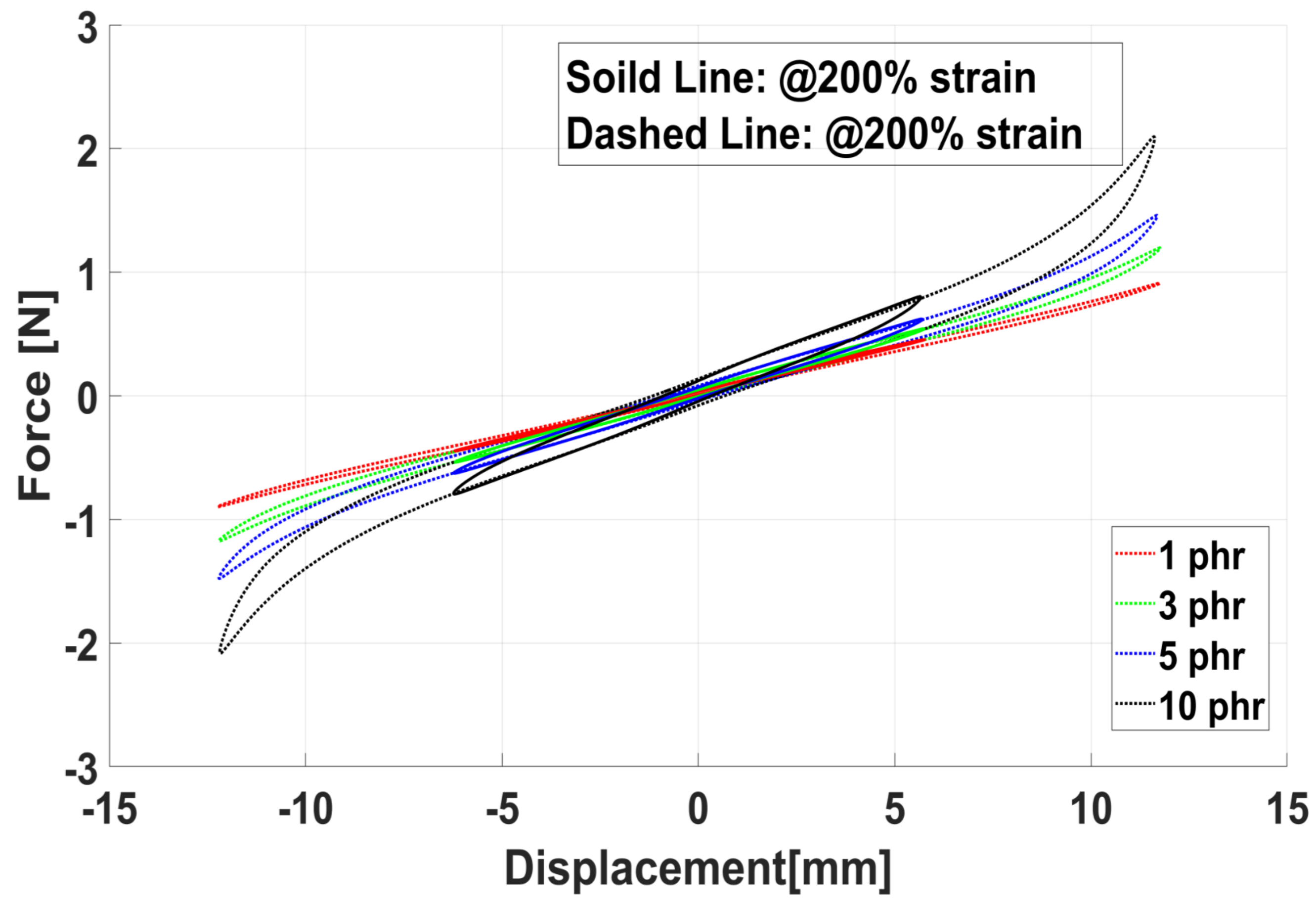
Rheometry

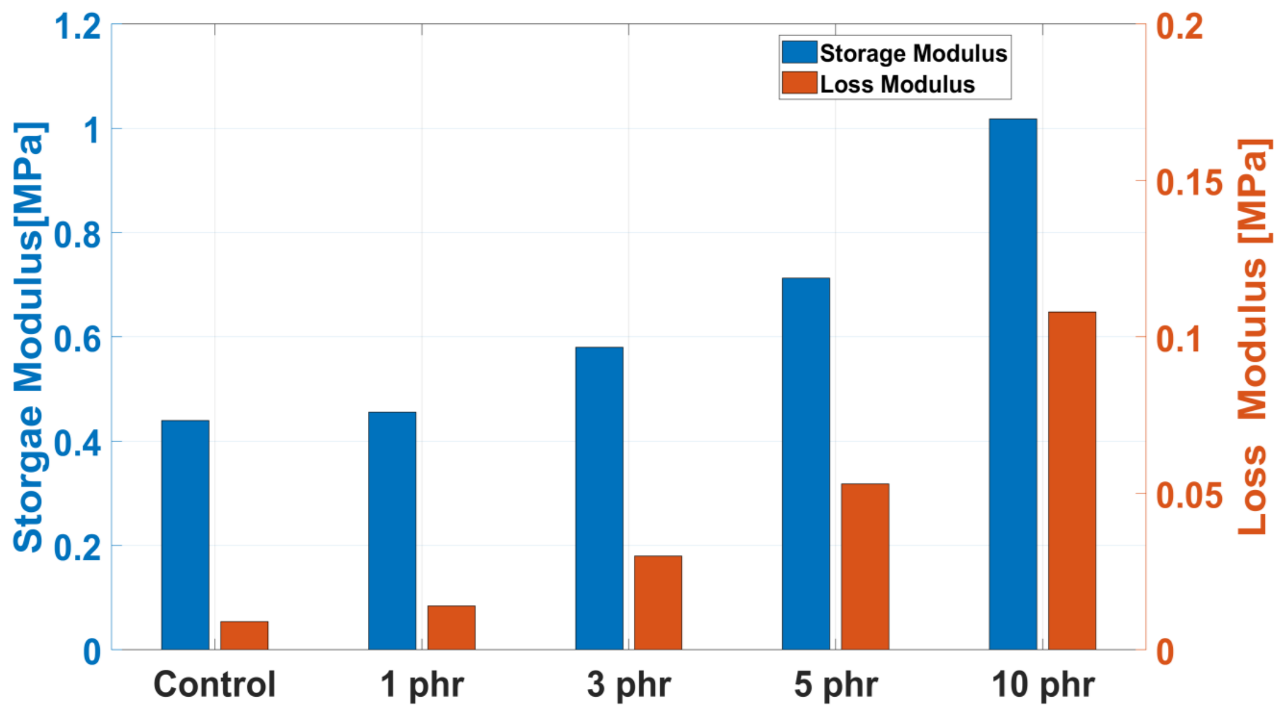
- The scorch time (ts2) is diminished as a function of CNTs loading indicating a premature vulcanization for filled rubber with respect to the control.
- Similarly, curing time (t90) is decreased as a function of CNTs increase.
- The minimum torque (ML) and minimum torque (MH) are raised in filled rubbers compared to the control manifesting enhancement of the stiffness in the filled rubber during cross-linking. The cross-link density (MH-ML) increased with the CNTs addition.



Dynamic shear test results

- Incorporation of CNTs into NR increases dynamic storage modulus and loss modulus.
- The energy dissipation increases in response of applied strain increase due to Mullins effect.
- Addition of CNTs enhances damping capability of the materials i.e. higher energy dissipation.





Conclusions & outlook

- CNTs addition into NR resulted in enhancement of energy dissipation, dynamic and loss moduli.
- ts2 and t90 were decreased whereas ML and MH were increased .
- Optimization of Cruciform samples to reach better degree of biaxiality during biaxial fatigue test.
- Comparison of different methodologies to reach a more homogenous CNTs dispersion.

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DTOcean+

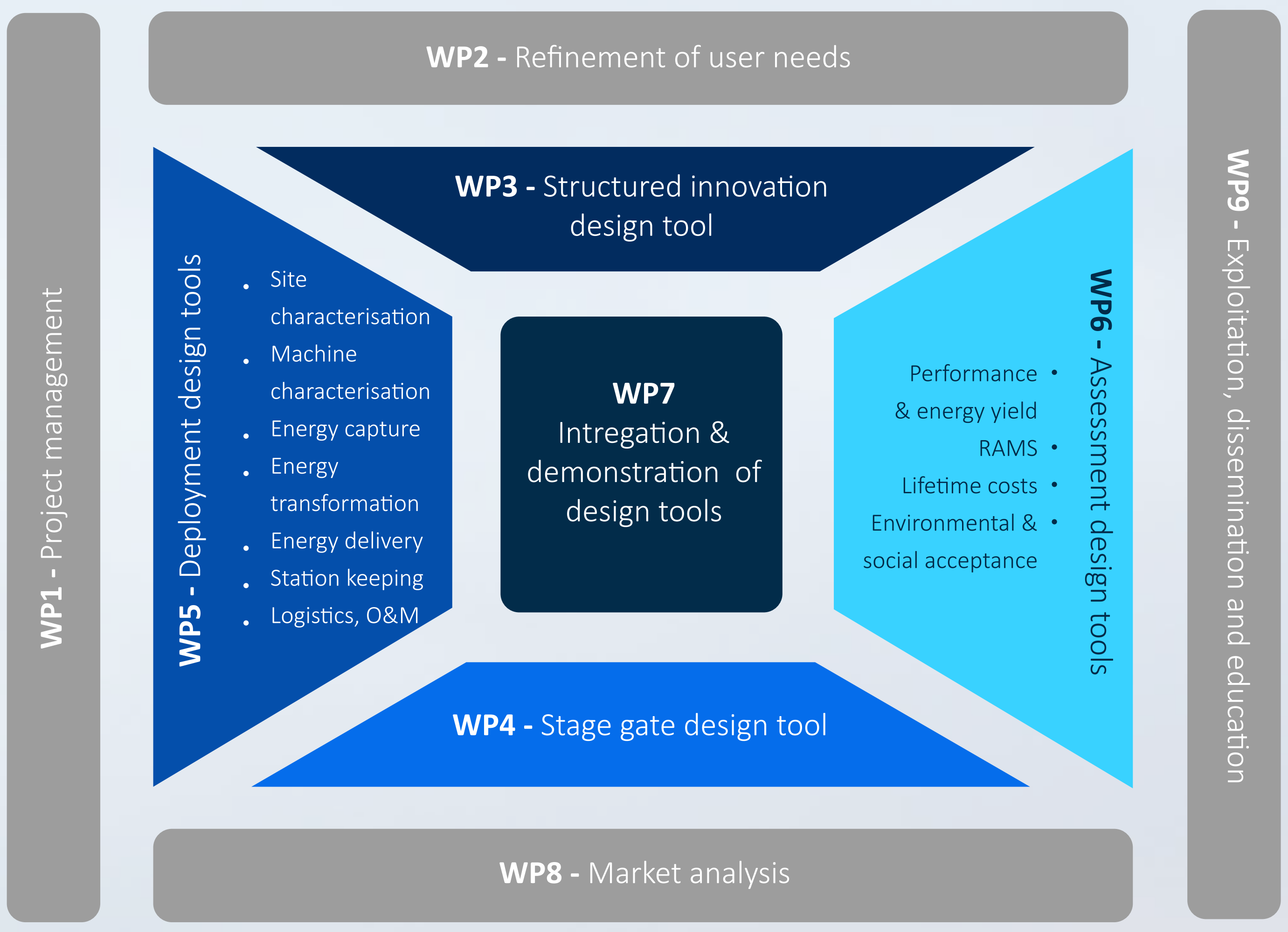
An advanced open source suite of tools for the selection, development, deployment and assessment of tidal and wave energy systems

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 785921.

Description

This **40-month project** (May 2018 – August 2021) with a total budget of **8 million euros**, followed **the development of DTOcean** which produced a first generation of freely available, open-source design tools for wave and tidal energy arrays.

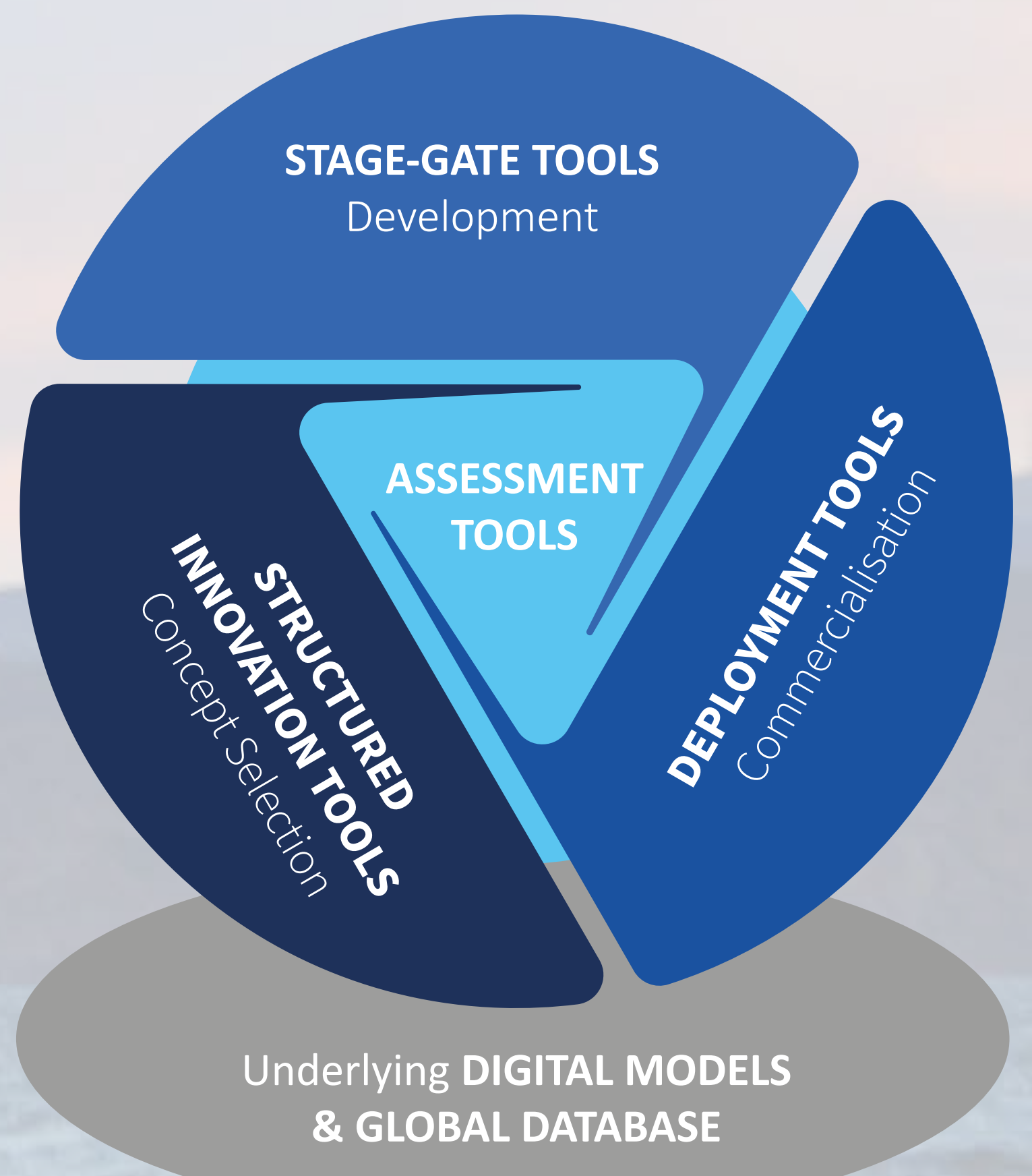
Structure



Objectives

- To support the **entire technology innovation process**, from concept to deployment
- To propose advanced design tools for **sub-systems, energy capture devices and arrays**
- To bring tools to TRL6 by demonstration scenarios **in real world cases**
- To make **freely available** tools as **open source** to the entire ocean energy sector
- To develop an integrated suite of tools that will be a **professional user-friendly** product

Results



- **Structured innovation design tool**
- **Stage gate design tool**
- **Deployment design tools**
  7 modules: Site characterisation, Machine characterisation, Energy capture, Energy transformation, Energy delivery, Station-keeping, Logistics and O&M
- **Assessment design tools**
  4 modules: Performance & Energy Yield, RAMS, Lifetime Costs, Environmental and Social Acceptance

Illustration credits: Nova Innovation, IDOM, Virtualys, Freepik - Design: France Energies Marines

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ORBITAL MARINE POWER
NEW by EDP & CTG
sabella ride the tide
Sandia National Laboratories
NREL NATIONAL RENEWABLE ENERGY LABORATORY