IMPACT

Innovative Methods for wave energy Pathways Acceleration through novel Criteria and Test rigs

Harnessing Ocean Power:
Progressing with WEC Technology through Rig Testing

Experience from design and execution of tests on Carnegie Clean Energy CETO 6 belt

European Commission

Experience from design and execution of tests on Carnegie Clean Energy CETO 6 belt

Agenda

- IMPACT project introduction
- Carnegie Clean Energy – company and products
- CETO 6 belt
- Application of IMPACT methodology framework
- Design of setup and tests execution
- Results and next steps

Horizon 2020 IMPACT project

Main objectives

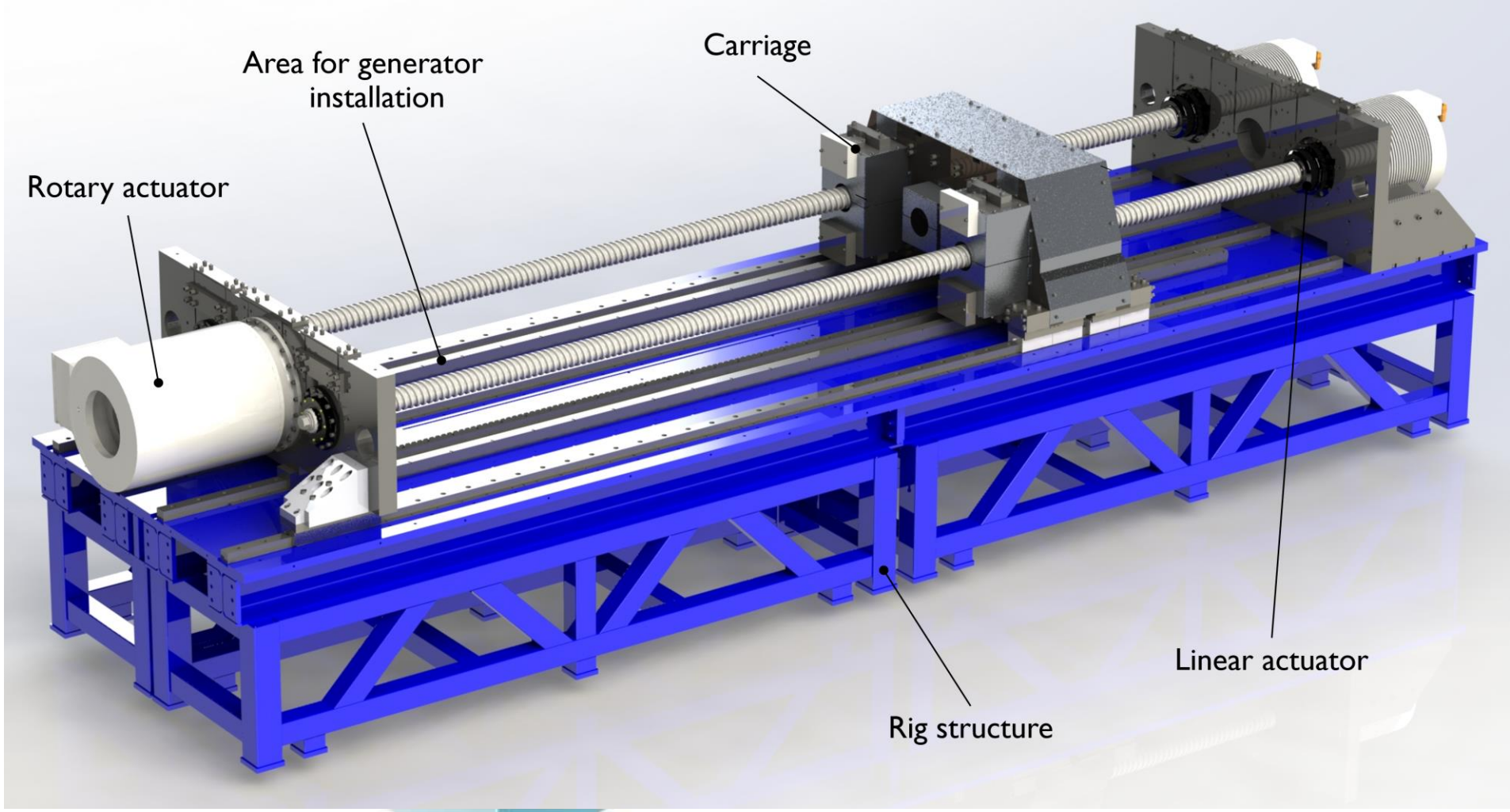
To design and manufacture **two novel test rigs covering** up to **75% of WEC subsystems affecting the device LCOE**

To identify **novel test criteria and metrics to reduce the test time** while **increasing the reliability of WEC technologies**

Horizon 2020 IMPACT project

Project sub-objectives

1. Design, development and fabrication of a **250 kW$_P$ drivetrain test rig** targeting conversion of **input mechanical** to **grid-compliant** energy:
   - mechanical drives
   - electrical generators
   - power converters
   - storage systems
   - grid-interface units
   - control system



Horizon 2020 IMPACT project

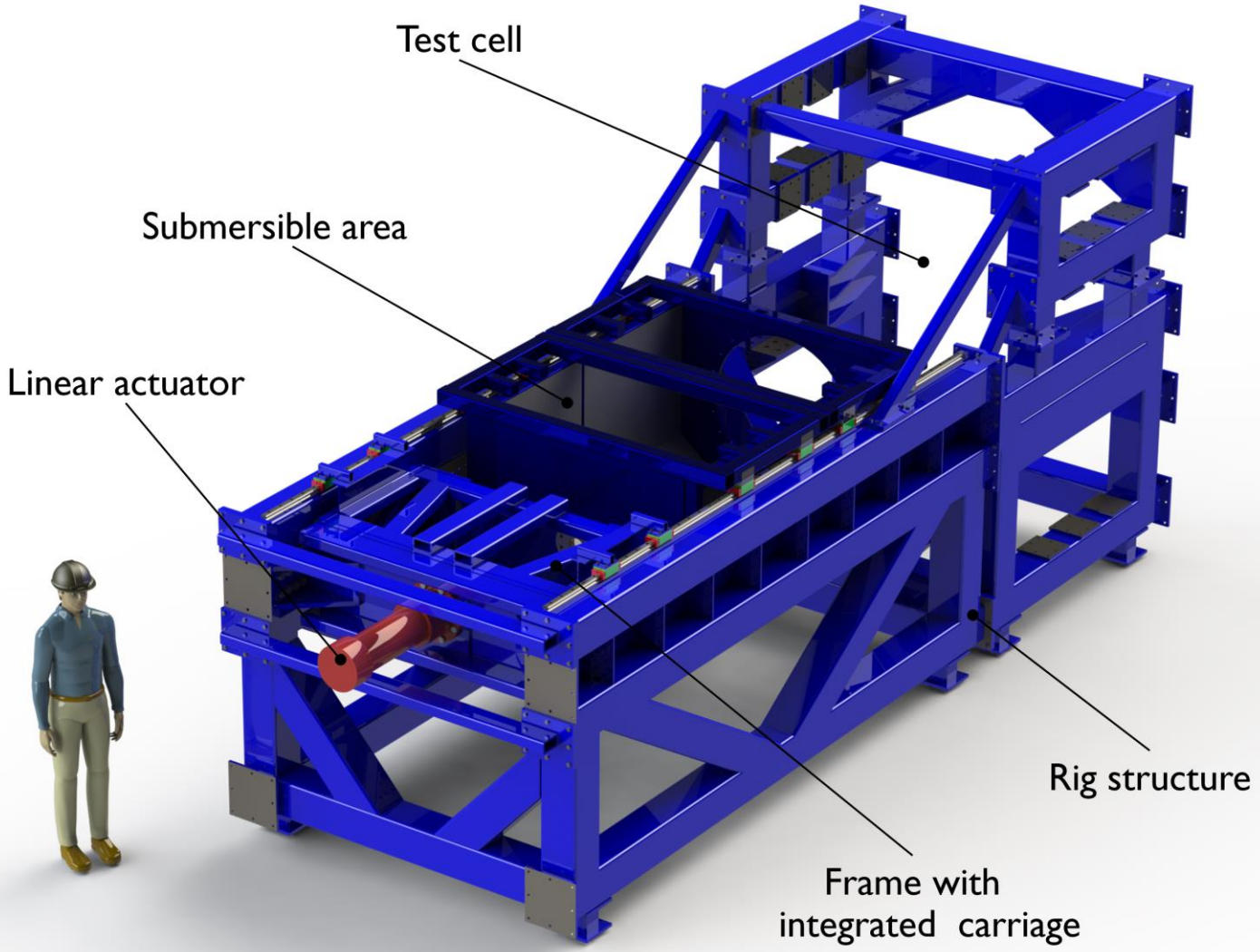
Project sub-objectives

2. Design, development and fabrication of a **structural components test rig** targeting:

- Mechanical interfaces
- Mooring lines
- Dynamic power cables
- Sealing systems

Both rigs allow:

- **Device Under Test characterization**
- **Hardware-In-the-Loop tests**
- **Accelerated tests**



Project sub-objectives

3. Design and commissioning of a **Dual Hardware-in-the-Loop (DHIL) testing platform**, to test two subsystems or components **simultaneously interacting with the WEC numerical model**

4. Definition of a **complete and thorough test approach** related to the identified WEC subsystems:

- **Novel methodologies**
- Clear, quantitative, **test-derived metrics**

5. **Demonstration** of the suitability of HIL rigs, DHIL testing platform, novel methodologies and metrics through a **test campaign involving subsystems of different device types**

Who is Carnegie (ASX:CCE)

Leading Australian Wave Energy Technology Provider with Global Presence

- Australian Stock Exchange listed wave energy technology company with 12,000+ shareholders (ASX:CCE)
- Portfolio of products:
  - CETO
  - MoorPower
  - Wave Predictor
  - Mooring Tensioner
- Track record and leading capabilities in wave energy: modelling, simulations, testing and offshore deployments
- Collaborative Engagement with Industry and Academia
  - Hewlett Packard Enterprise: Reinforcement Learning Controller

Carnegie CLEAN ENERGY

Products: MoorPower

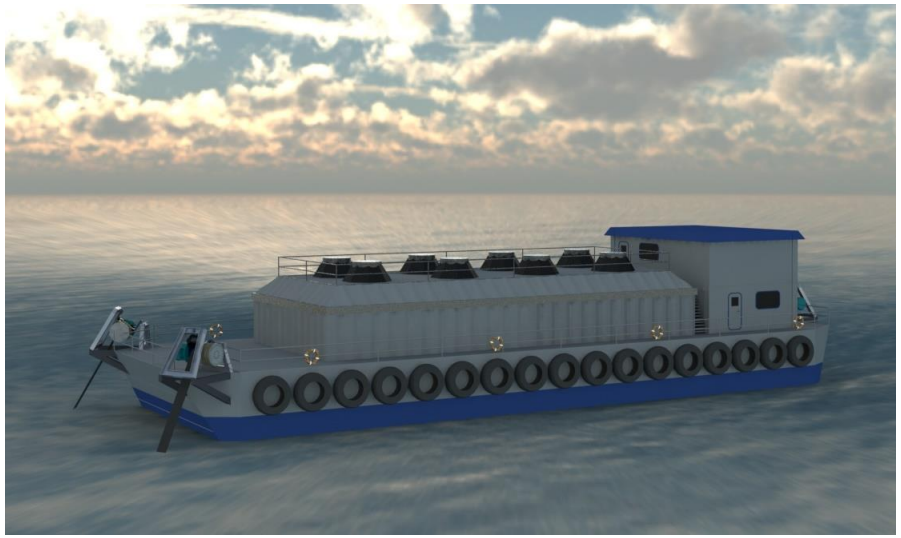
Spin-off Wave Energy Converter for Offshore Demand Applications

Product

- MoorPower is wave energy converter for offshore demand
  - Aquaculture **moving further offshore** into more energetic waters
  - Large feed barges have **MWs of demand**
  - Allows customers to **capture the wave energy** already interacting with structures
  - **Reduces or removes need for diesel generation**

Projects

- MoorPower Scaled Demonstrator Deployment in Western Australia in August
- Commercial Demonstrator in Tasmania with major aquaculture partner Huon or Tassal
- BlueEconomy Cooperative Research Centre



Products: CETO

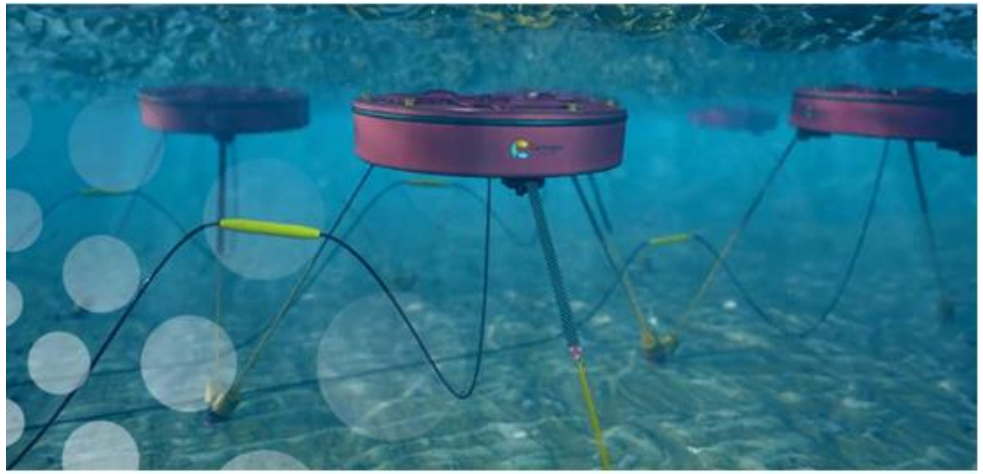
Wave Energy Converter for Large Grid and Remote Markets

Product

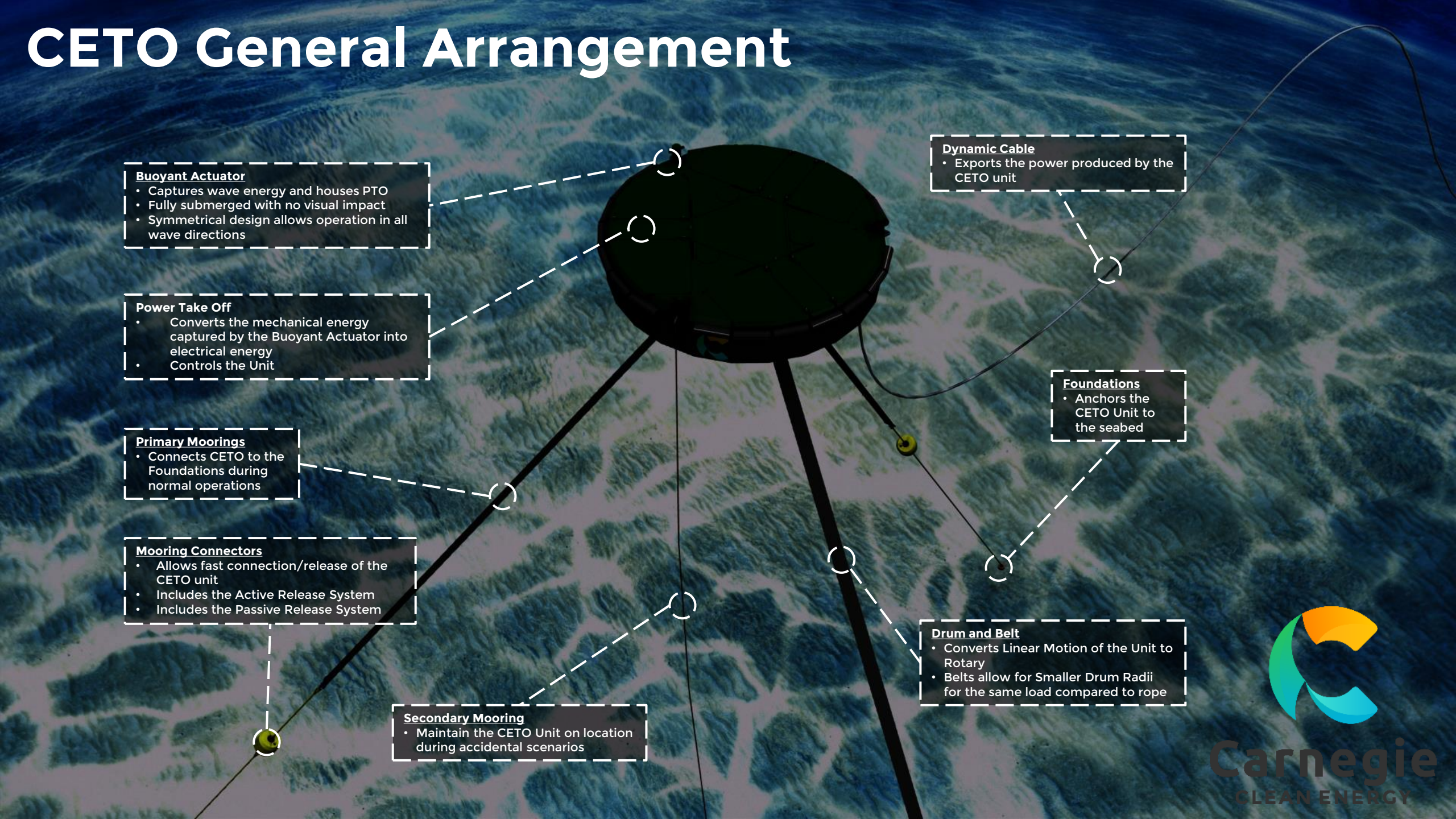
- 1MW Submerged point absorber
  - Operates below the surface
  - Electric Power Take-Off
  - Intelligent Control
  - Optimised
  - Track Record
  - Complementarity

Projects

- EuropeWave Scaled CETO Deployment in 2025
  - EuropeWave Phases 1 and 2 Completed. Phase 3 underway.
- Future CETO Project Roll Out
  - Discussions with strategic partners
  - Including with a large European Utility partner who expressed interest in West Coast of US



CETO General Arrangement



Buoyant Actuator
- Captures wave energy and houses PTO
- Fully submerged with no visual impact
- Symmetrical design allows operation in all wave directions

Power Take Off
- Converts the mechanical energy captured by the Buoyant Actuator into electrical energy
- Controls the Unit

Primary Moorings
- Connects CETO to the Foundations during normal operations

Mooring Connectors
- Allows fast connection/release of the CETO unit
- Includes the Active Release System
- Includes the Passive Release System

Secondary Mooring
- Maintain the CETO Unit on location during accidental scenarios

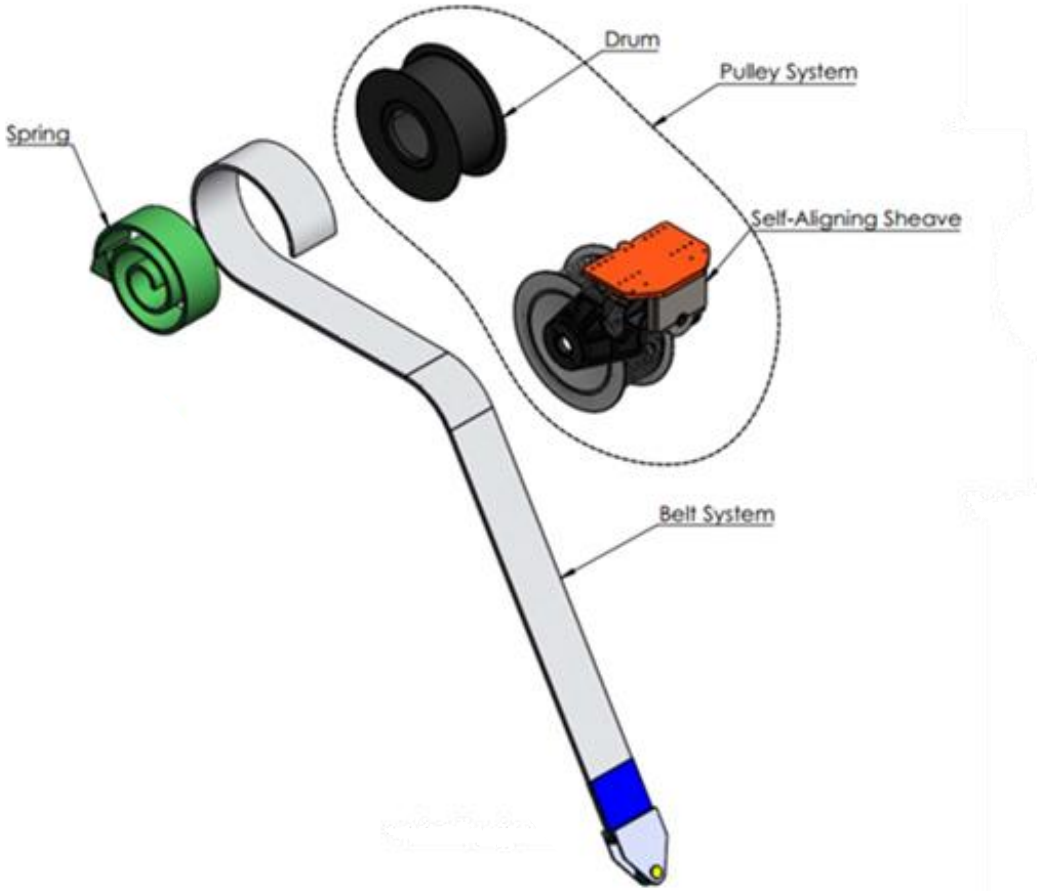
Dynamic Cable
- Exports the power produced by the CETO unit

Foundations
- Anchors the CETO Unit to the seabed

Drum and Belt
- Converts Linear Motion of the Unit to Rotary
- Belts allow for Smaller Drum Radii for the same load compared to rope

Carnegie
CLEAN ENERGY

Translation System



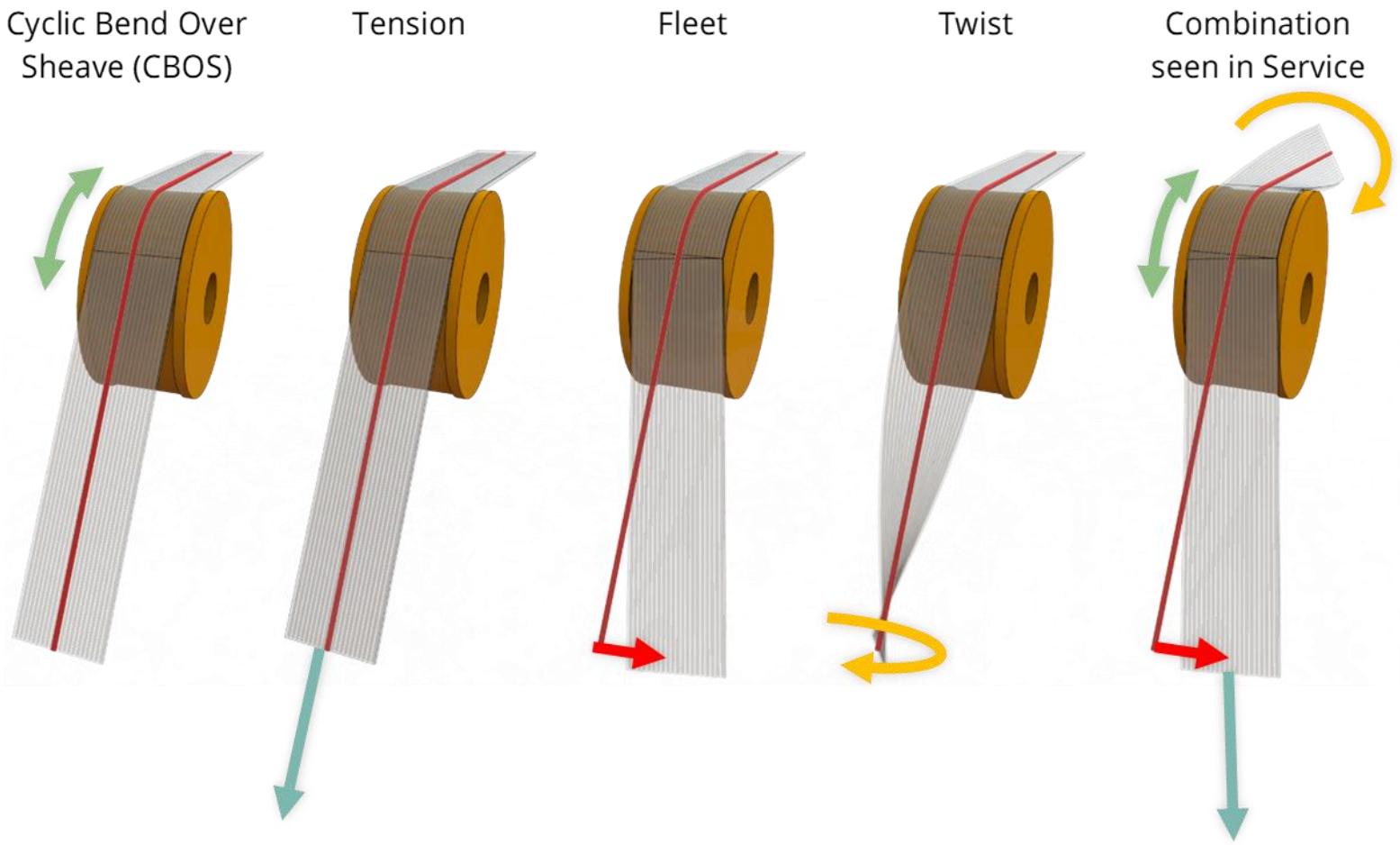
- Converts Linear Motion of BA to Rotary Motion in the Drum
- Rotary Motion is then Converted to Electricity via the Electric Powertrain
- Mooring Tensioner (Spring) in Parallel
  - Provides a Torque to Offset Buoyancy
  - Is Efficient
  - Avoids overheating/Power Loss in Motor/Generator
- Self Aligning Sheave to ensure:
  - Only Twist in the Internal Belt
  - Minimise Fleet in External Belt

Definition of accelerated test conditions

- CBOS cycles counting (MATLAB)
- Fleet Determination (via Dynamic Simulation)
- Belt characteristics and modelling (e.g. stiffness, deformation torque)

Belt Degradation Mechanisms

- Cyclic Loading ~4m per Year
- Combination loading
- Saltwater Environment
- Marine Life / Growth
- Particulates



Novel Testing Methodologies

The IMPACT Methodology Framework

Focus on the following subsystems / components:

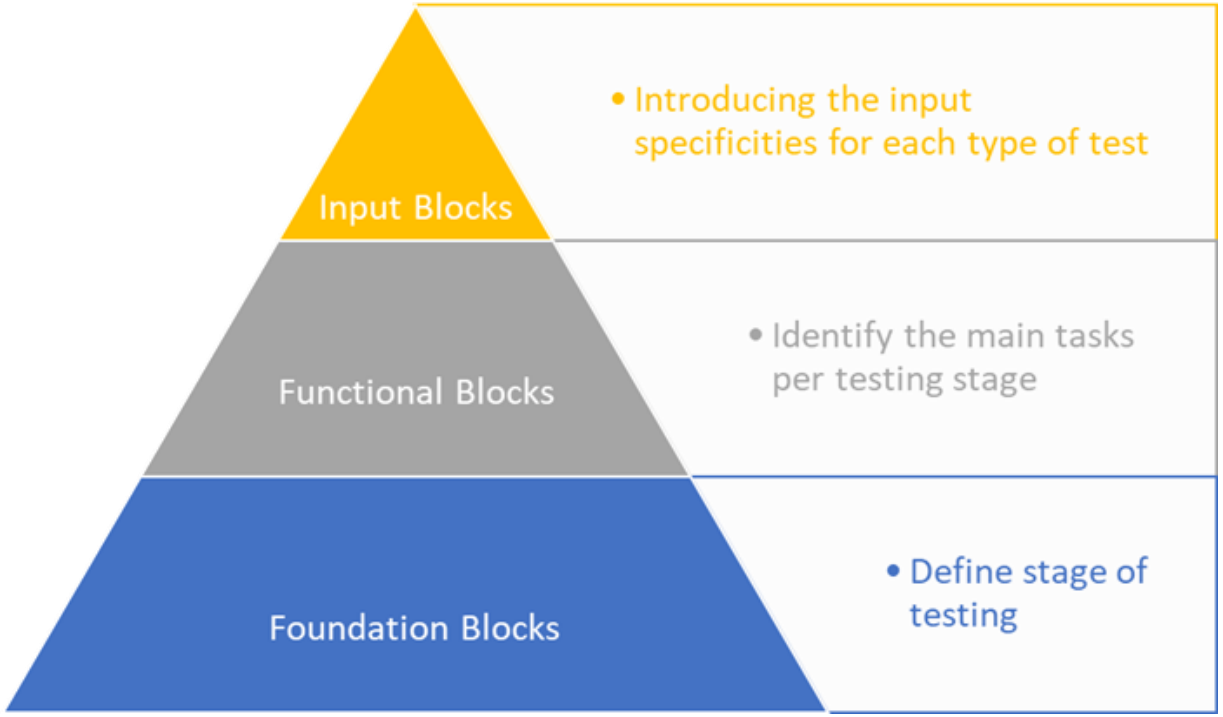
- PTO (both linear and rotary).
- Mechanical interfaces e.g. joints, welds etc.
- Mooring lines (or elements of these).
- Dynamic power cables.

Focus on the following Evaluation Areas:

- *Performance*, *Reliability*, *Survivability*.

The methodology framework is composed by three layers of 'building blocks':

- *Foundation blocks*, which specify the stage of the testing programme.
- *Functional blocks*, which relate to the main tasks at each stage.
- *Input blocks*, where specific inputs to each Functional block are introduced.



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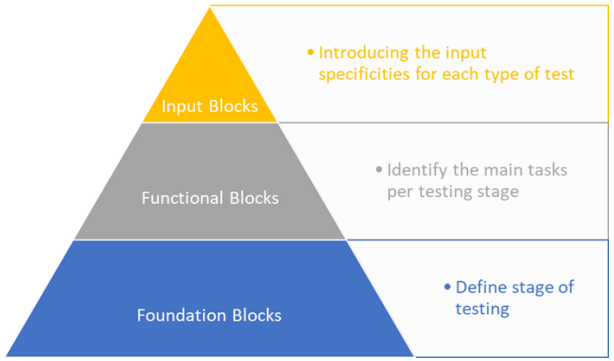
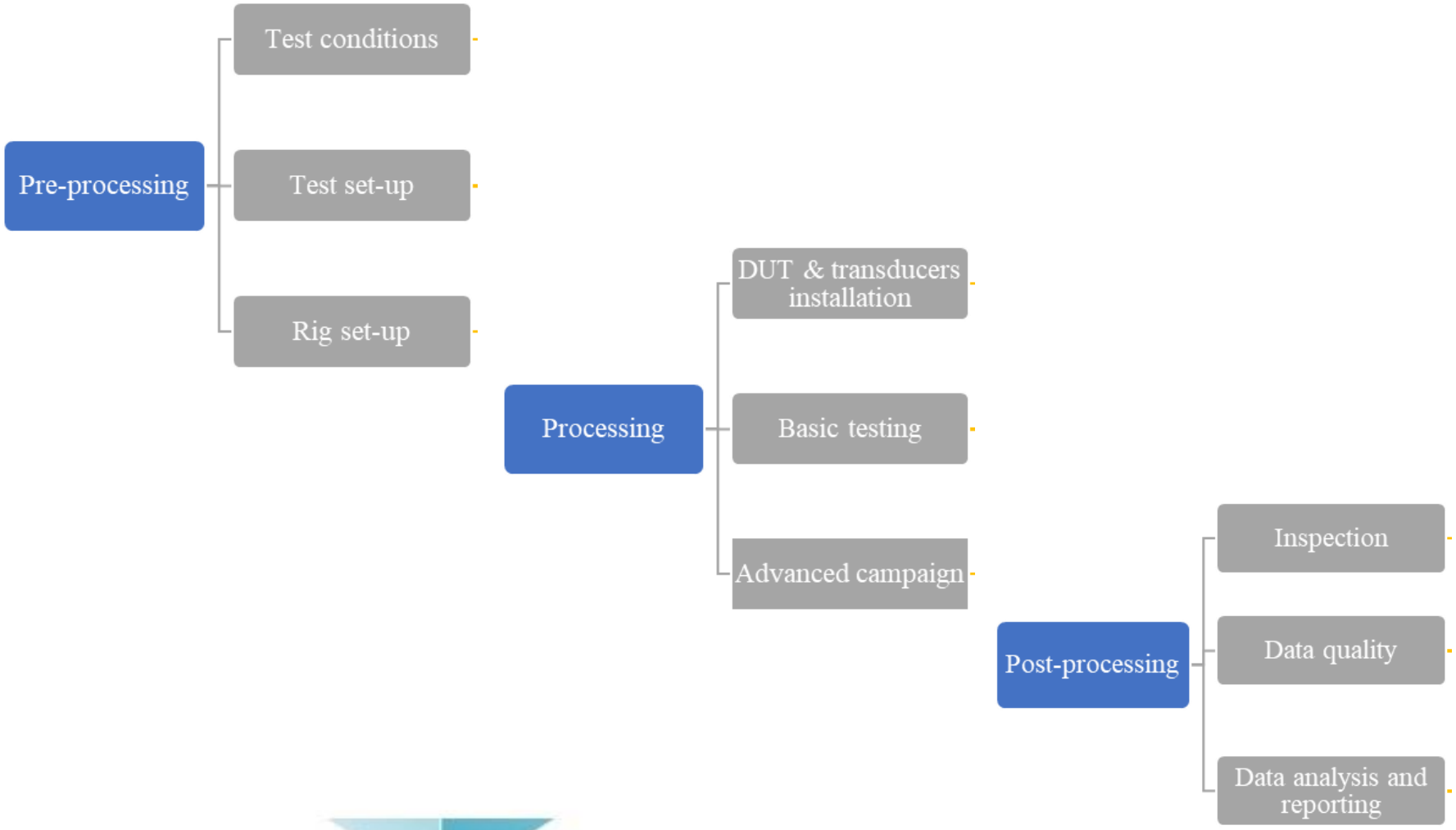




Framework based on two testing approaches:

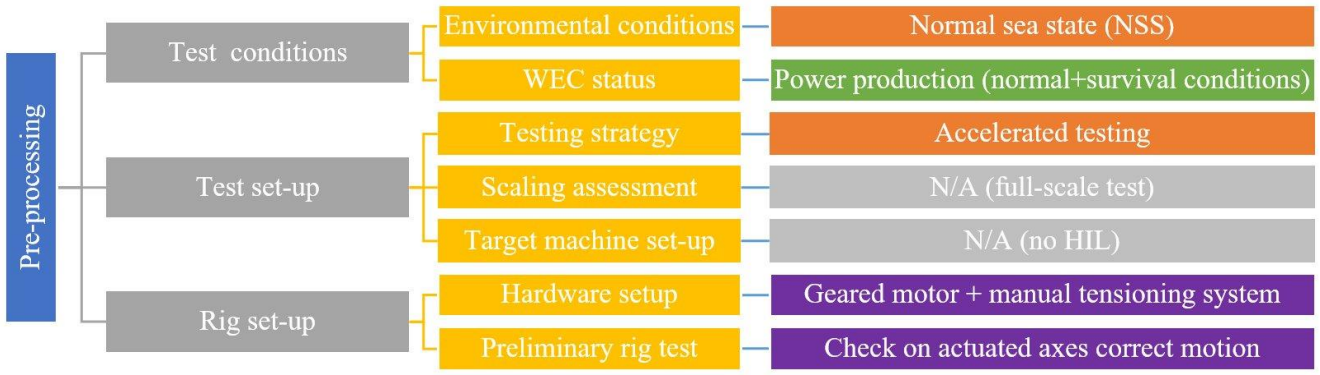
- Dual Hardware-In-the-Loop (DHIL) testing
- **Accelerated testing**

Novel Testing Methodologies

Case study: Carnegie CETO 6 belt accelerated testing

Example of Building Blocks applied to Carnegie CETO 6 belt accelerated testing (DLC 1.1 – Power production conditions)

- Pre-processing stage.



Normal Sea State (NSS) -> define instantaneous wave elevation

Belt is unloaded in other states -> adapt WEC numerical model

Build on concept of DEL (QuanAT) -> define load amplitude & nr. of cycles

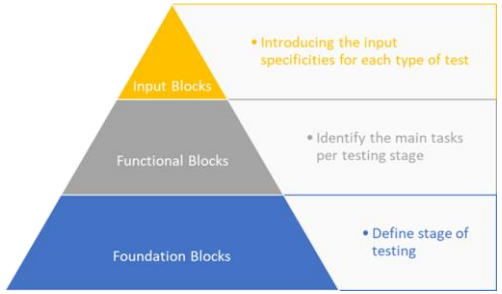
Load 'demand' vs rig 'supply' -> assessed no need of scaling

HIL / DHIL approach not suitable -> no need to set-up real-time machine

Setup rig with all hardware for planned test

Calibrate actuation system based on load inputs

Modelling method: Theoretical | Numerical | Experimental



Building block: Foundation | Functional | Input

Novel Testing Methodologies

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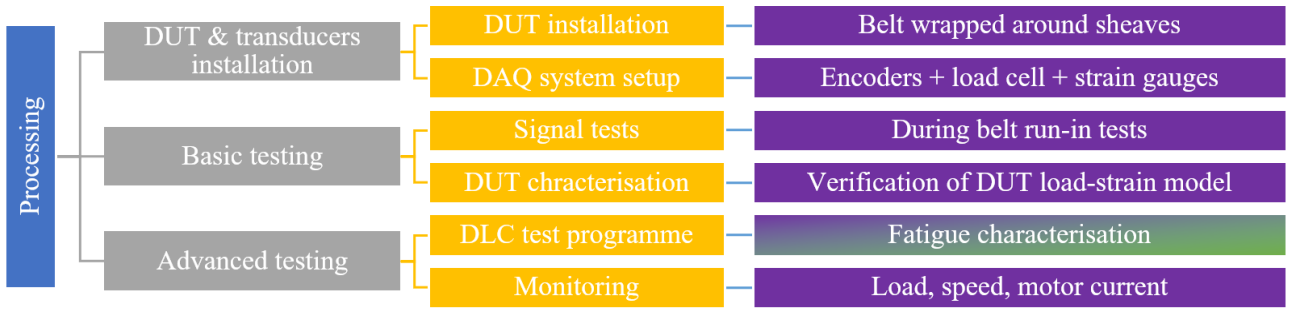

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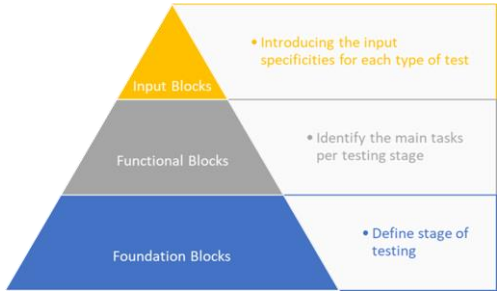

Building block: Foundation | Functional | Input

Novel Testing Methodologies

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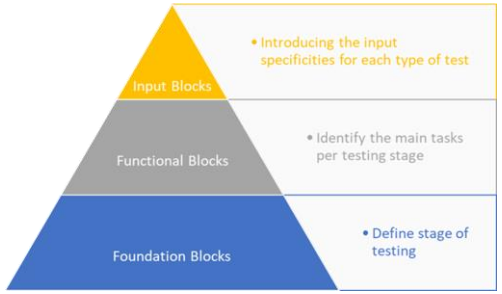
Example of Building Blocks applied to Carnegie CETO 6 belt accelerated testing (DLC 1.1 – Power production conditions)

- Post-processing stage.

Post-processing	Inspection	DUT status	Visual inspection	Conduct visual inspections on belt (especially on edges)
		Rig status	Visual inspection	Conduct visual inspections and check backlash on components
	Data quality	Data quality check	Data duplicates, missing data, bias etc	Check quality of data – repeat test if required
		Raw data filtering	N/A	No filtering required
	Data analysis and reporting	Metrics assessment	Theoretical fatigue curve	Assess parameters describing the fatigue curve
		Uncertainty assessment	Consider measurement, analysis, setup errors	Evaluate uncertainty during the entire testing process
		Reporting	Characterization- and reliability-driven	Finalise test reports

Modelling method: Theoretical | Numerical | Experimental

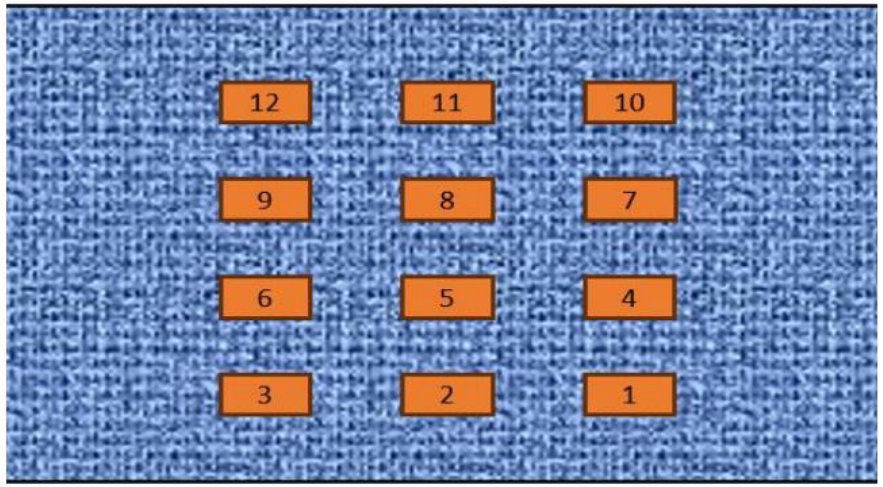


Building block: Foundation | Functional | Input

Novel Testing Methodologies

Test plan

- Preliminary tension-tension testing (smaller-scale prototype)
- DUT characterization
  - Static testing;
    - Load-deformation characteristic, also varying fleet and twist
    - Creep when loaded and unloaded
  - Tracking testing: checking eventual lift off and transversal motion at high speeds and low loads
- Endurance testing: simulating damage on belt simulating two years of deployment time



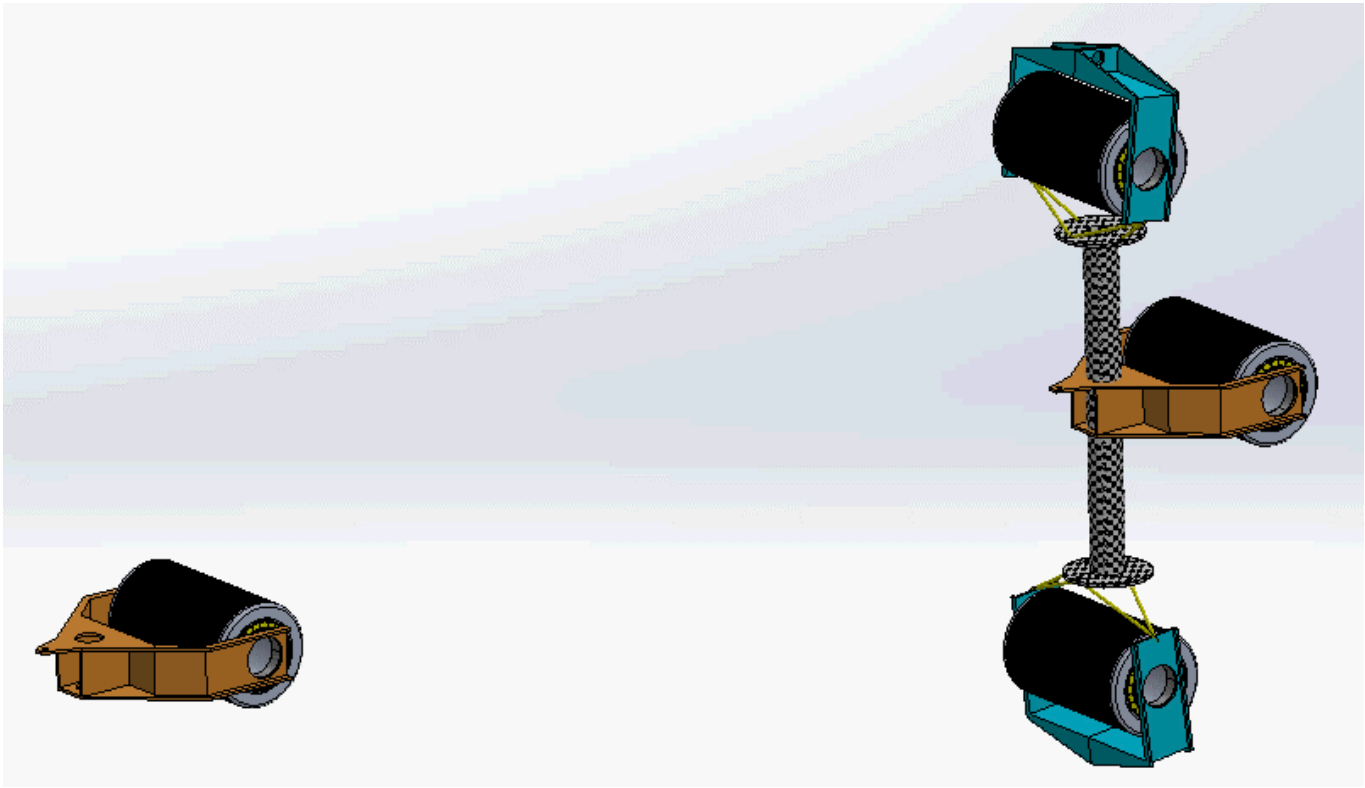
Strain gauges array schematics to be applied on belt during characterization

Endurance test plan

Test Setup

Concept

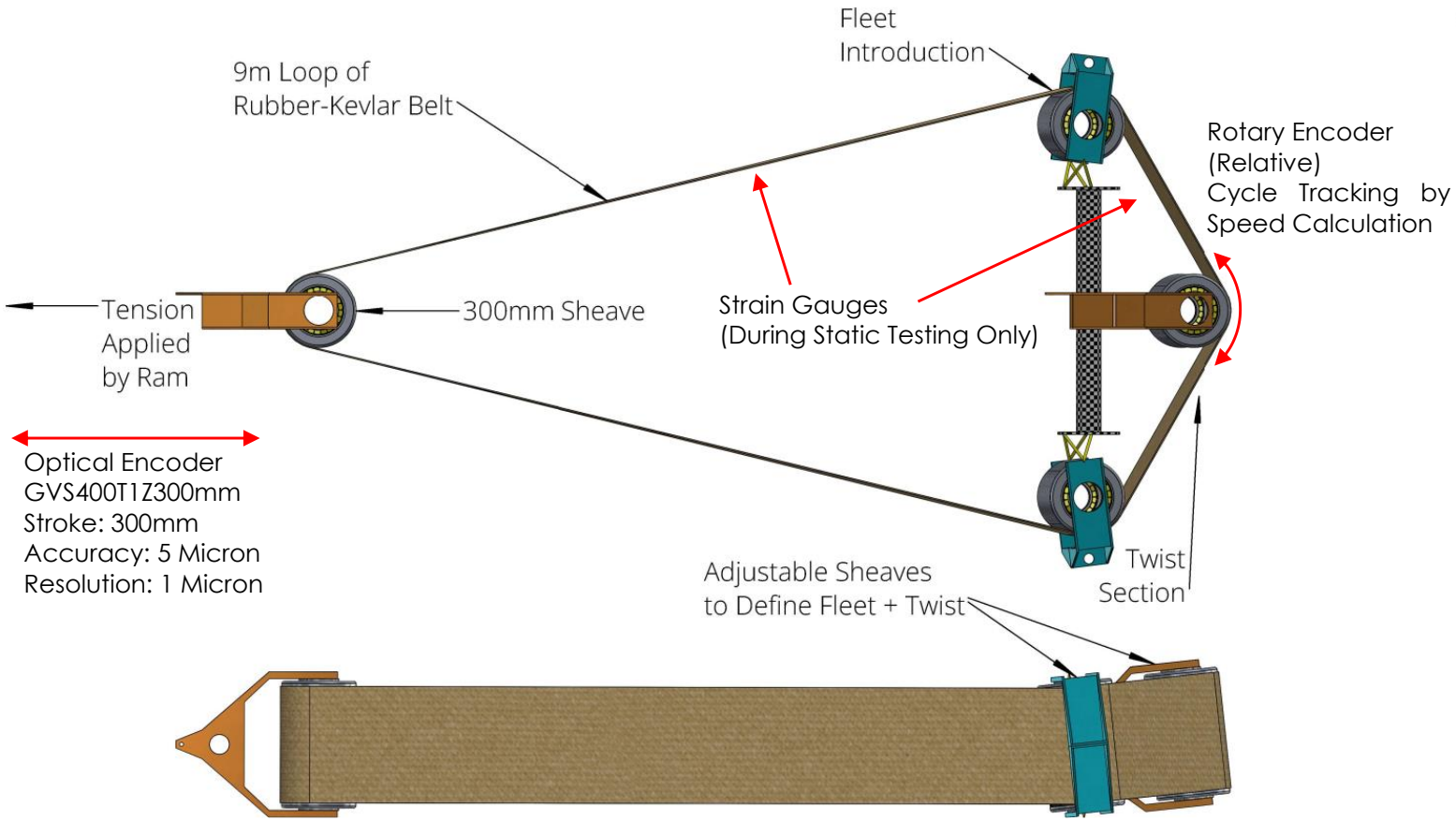
- To use a closed-loop belt wrapped around four sheaves
- Fleet and twist angles to be changed according to the tested configuration

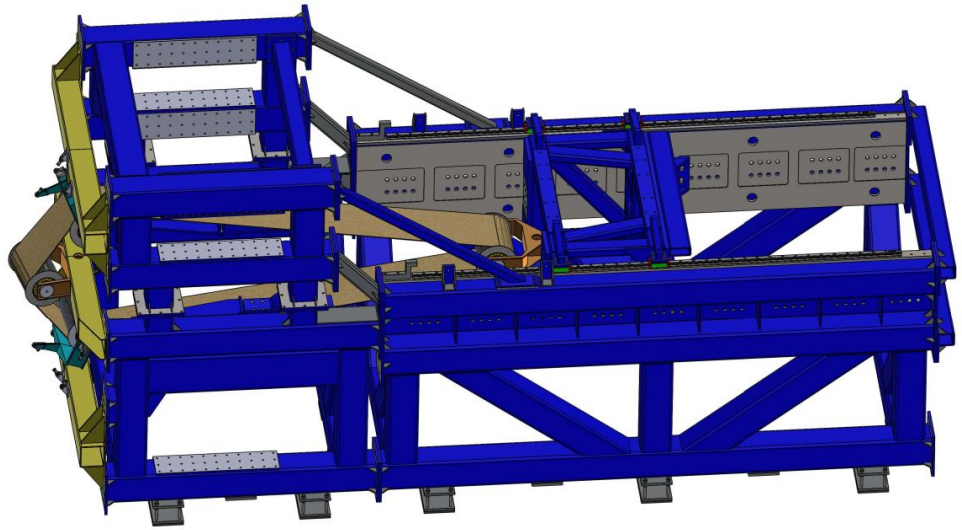


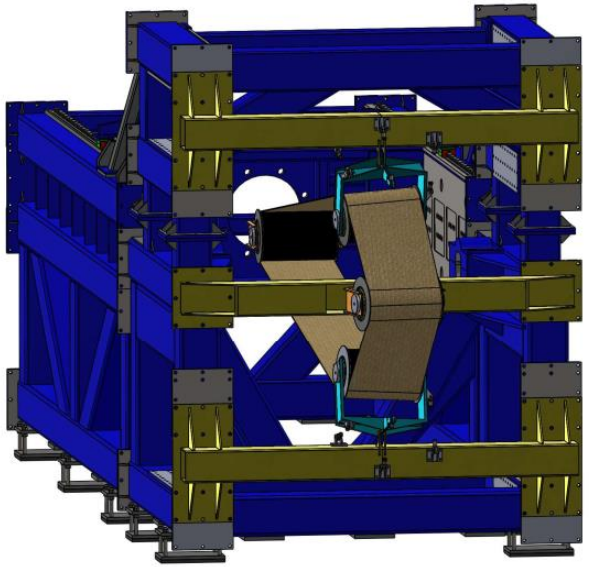
Test Setup

Implementation of concept

- Drafted a preliminary version of the setup interfaces
- Identified sensors to be used



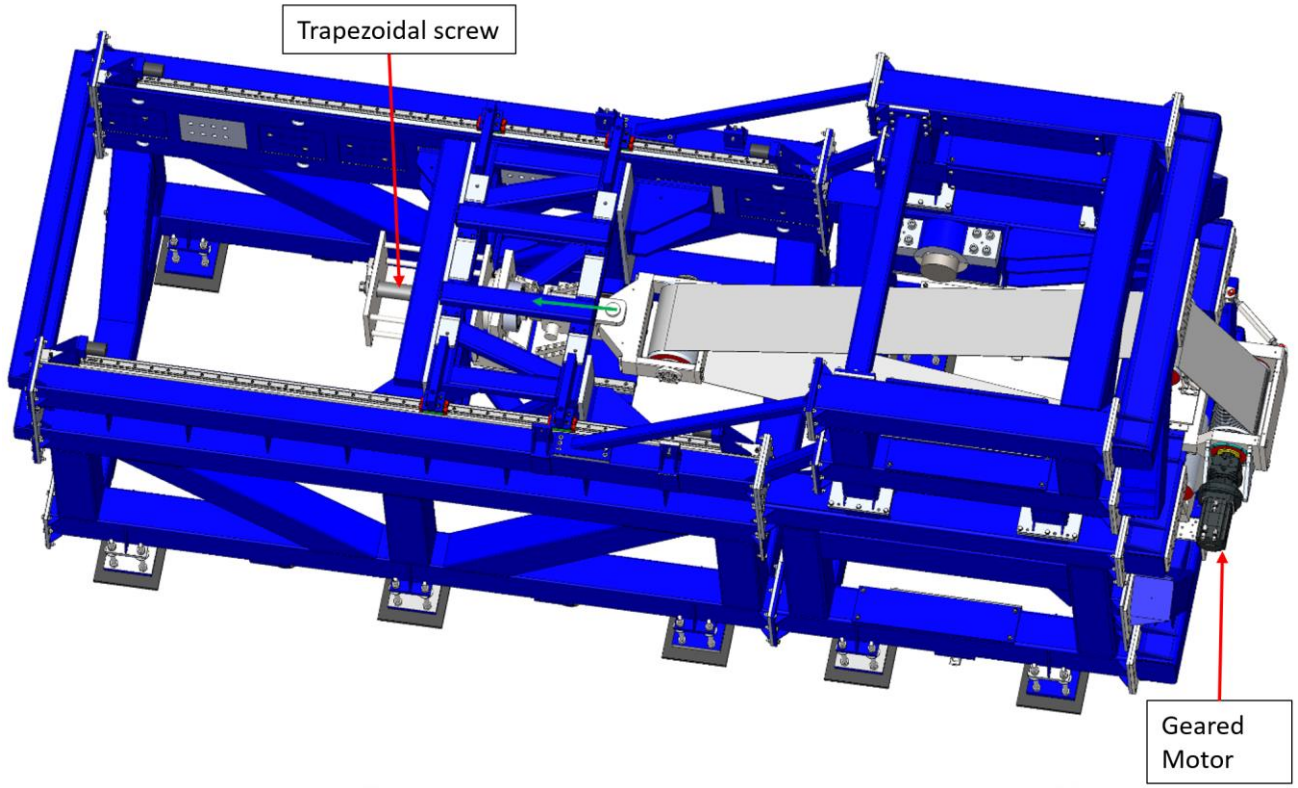


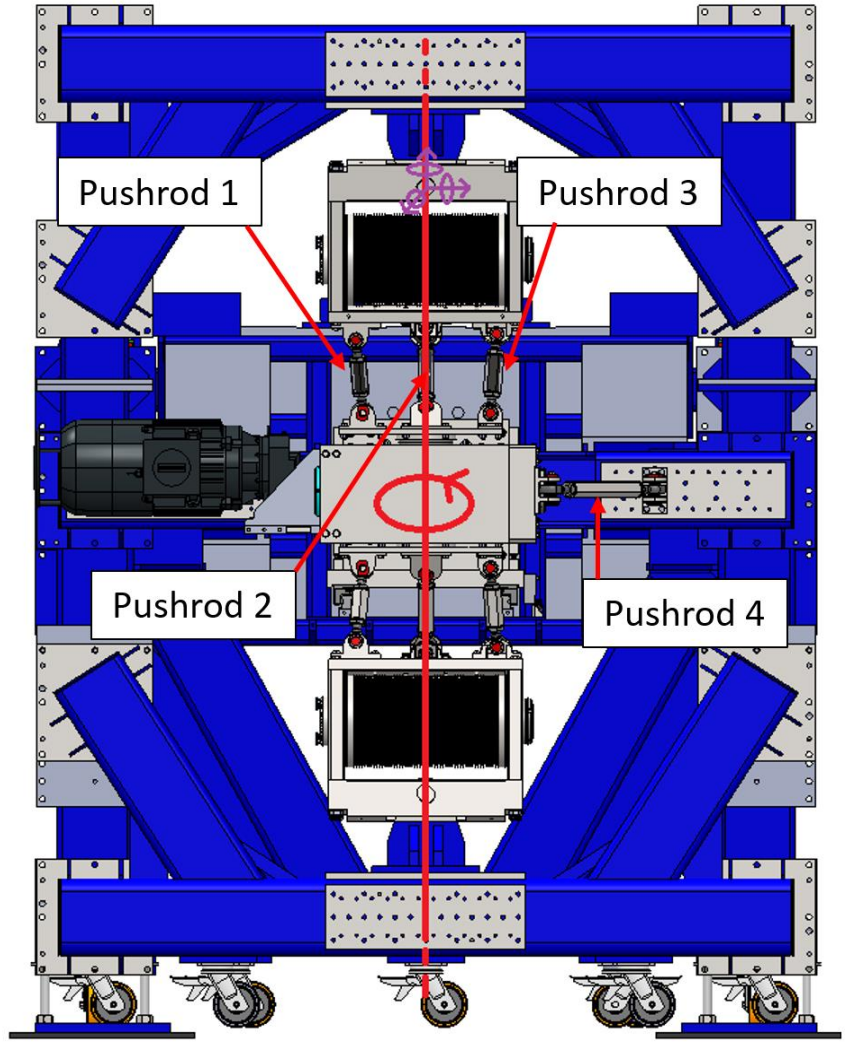


Test Setup

Implementation of concept

- Trapezoidal screw used to apply static load (to be adjusted between each test)
- N.3 pushrod and one spherical joint used to allow the 3D rotation of upper and lower sheaves
- N.1 pushrod to set the fleet angle





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- N.1 pushrod to set the fleet angle

Test Execution

Static testing

- Tracking of deformation along belt length

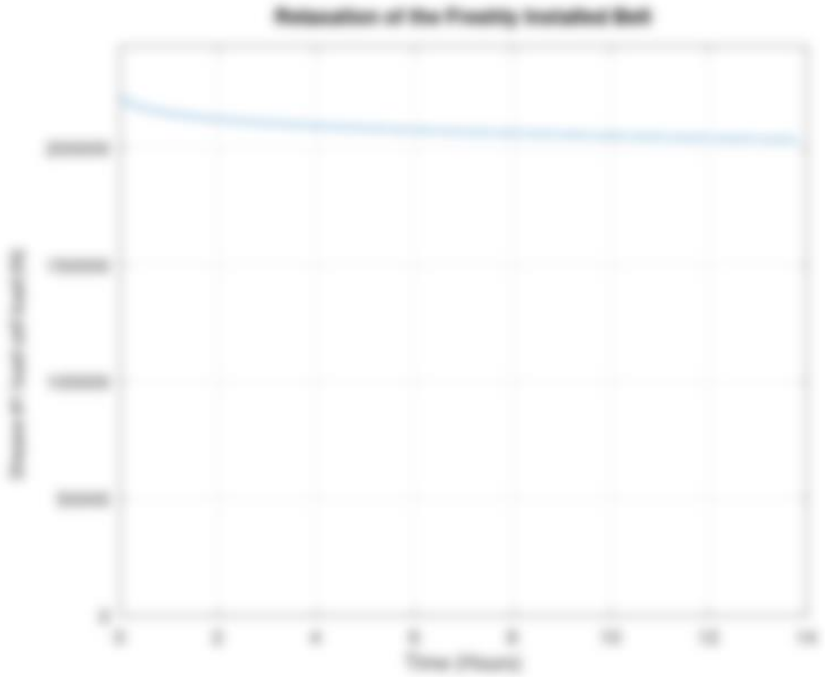
Test Execution

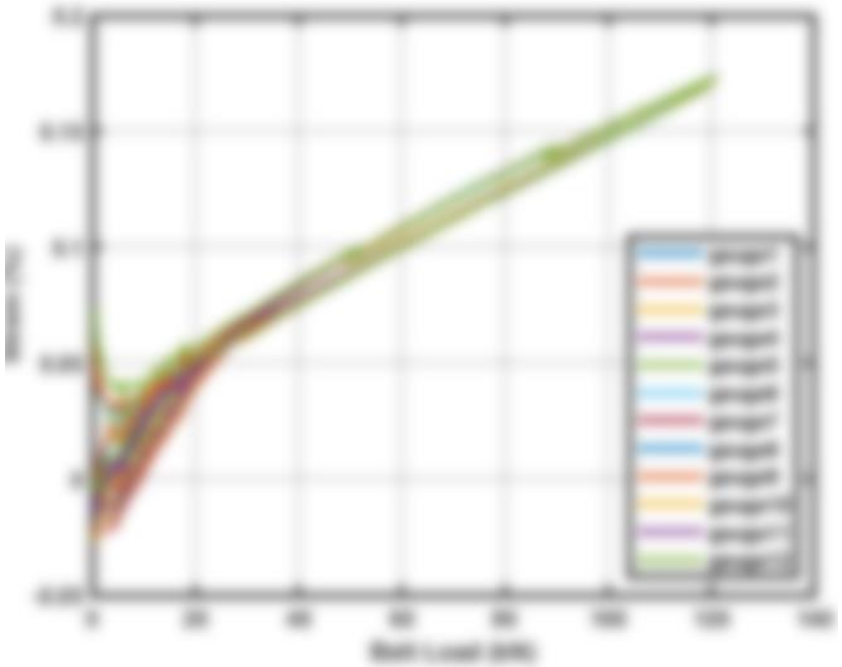
Dynamic testing

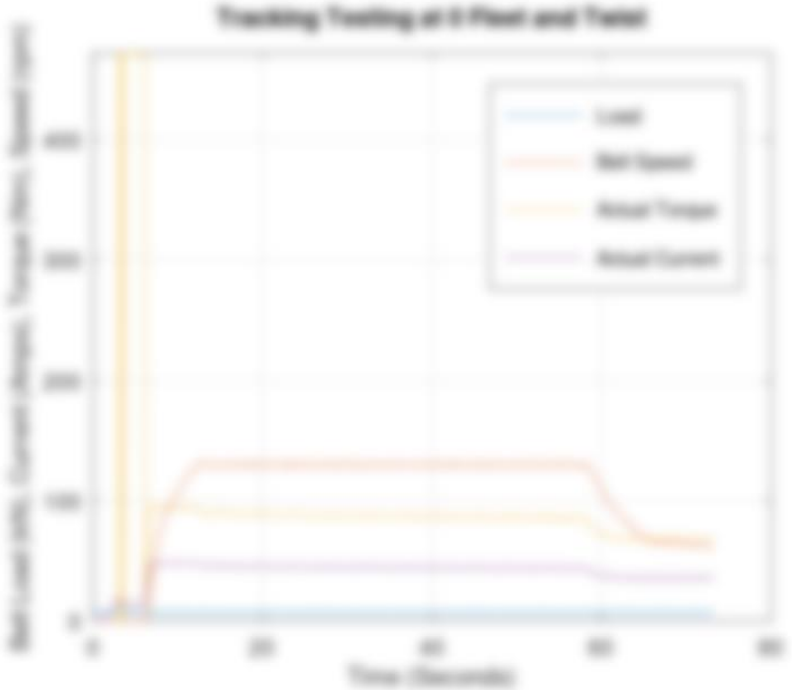
- Run-in of belt

Results

- Creep behavior observed, either when loading and unloading
- Load-Strain curve measured for all the gauges
- Dynamic behavior reproduced by cycling the belt

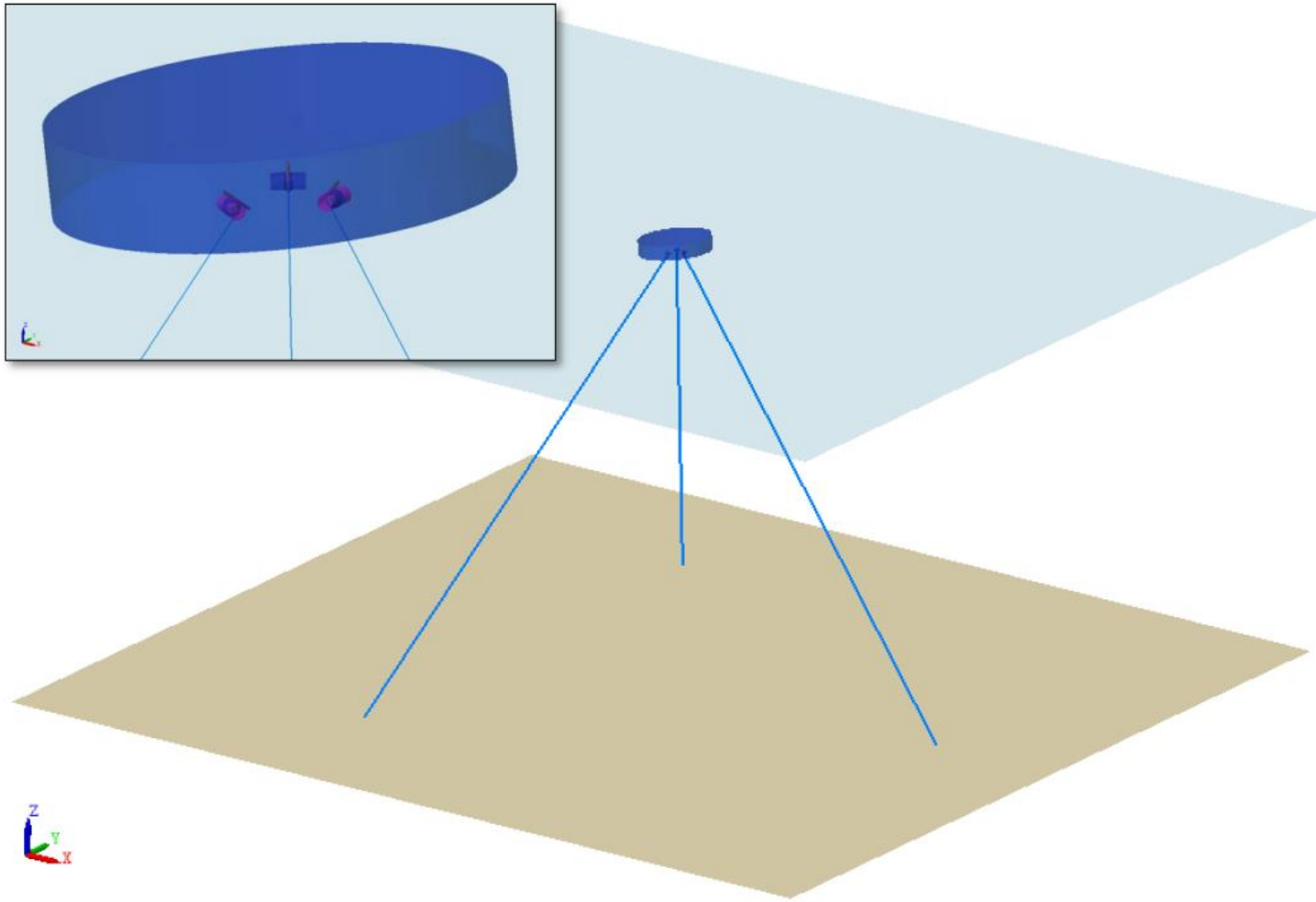






Next steps

- Terminate endurance tests
- Execute post-test inspections
- Update WEC model with belt test results



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VGA

Carnegie CLEAN ENERGY

EUROPEWAVE

SINTEF

UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh

YAVIN FOUR CONSULTANTS

This project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007071.

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VGA SINTEF YAVIN FOUR CONSULTANTS UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh MaREI Energy · Climate · Marine

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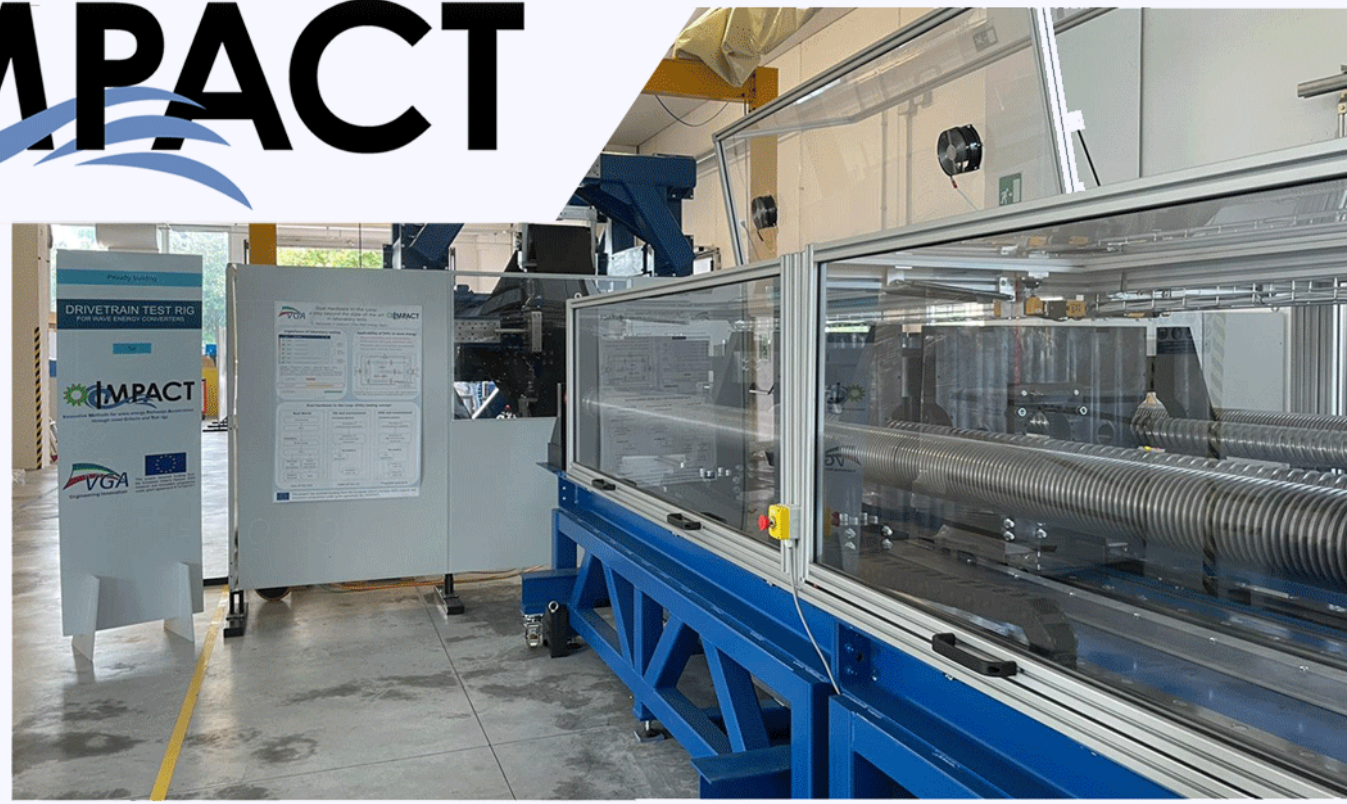

12 April 2024

Perugia, Italy

Wave Energy Rig Testing Workshop

Programme

14:00-14:05 Welcome

Paula Garcia Rosa (IMPACT/SINTEF)

14:05-14:30 VALID session

WEC hybrid testing: Lessons learned from IDOM's case study

Iván Ruibal (IDOM)

Eider Robles Sestafe (Tecnalia)

14:30-14:55 IMPACT session

Experience from designing and executing tests on Carnegie Clean Energy's CETO 6 belt

Giacomo Alessandri (VGA)

Sam Neilson (Carnegie Clean Energy)

14:55-15:25 Panel discussion and Q&A session with the presenters

Moderator: Claudia Sans (VALID/Aquatera)

15:25-15:30 Close

Paula Garcia Rosa (IMPACT/SINTEF)