EnFAIT

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ENFAIT
ENABLING FUTURE ARRAYS IN TIDAL

Test Plan

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Contents

1 Introduction

A Funding Grant was awarded from the European Union's Horizon 2020 research and innovation programme in January 2017 to demonstrate a grid-connected tidal energy array at a real-world tidal energy site, propelling tidal energy towards competing on a commercial basis with alternative renewable sources of energy generation – Enabling Future Arrays in Tidal (EnFAIT). This was in response to the call *LCE-15-2016: Scaling up in the ocean energy sector to arrays* to generate significant learning through demonstration of cost-effective tidal arrays.

This document is produced to define key performance indicators for both individual turbines and the overall array; outline the systems to record these metrics, including automatic report generation wherever practicable; and outline a test plan for how to operate the array of turbines to maximise learning over the duration of the project. It is also to be submitted to satisfy deliverable D6.1 of the EnFAIT project and to be made available for public dissemination.

An overview of the project follows, supplemented by outline descriptions of each test phase and the key performance indicators that will be used to evaluate and optimise performance of the array. Finally, a schedule of activity is presented and relevant appendices are included.

This test plan and the approach to be taken by EnFAIT will be developed further as the project progresses.

2 Background

The EnFAIT project is being delivered by a consortium of European organisations that will demonstrate a grid connected tidal energy array at a real-world tidal energy site, propelling tidal energy towards competing on a commercial basis with alternative renewable sources of energy generation. This project builds on the considerable body of work delivered by the project partners, including the successful deployment of three grid-connected prototype tidal turbines in the Bluemull Sound, Shetland which is the site to be used for this project.

Demonstrating significantly reduced lifetime cost of energy (LCOE) and mastery of risks at the project level will boost the confidence of potential clients and investors, giving European tidal energy developers a springboard into an emerging global market. In addition, this ground-breaking project will generate significant "learning by doing", which will be disseminated to benefit the wider European ocean energy industry. This project is designed to generate common, fundamental learning that is not specific to one type or scale of technology, but is immediately applicable to the wider ocean energy sector. The project will showcase the positive impact of ocean energy on the natural environment and local community, highlighting the huge potential benefits of the sector for European industrial output and employment.

With a total of six turbines, the EnFAIT project will be the largest number of devices ever deployed in an ocean energy array. The project builds on an existing operational site, minimising development risk and allowing the generation of real-world results from day one. The technology used in the array has 100% EU content. The layout of the turbines in the array will be adjusted within the project, enabling array interactions and optimisation to be studied for the first time at a real tidal energy site.

3 The Consortium

The inherent challenges of the project require a consortium team with complementary competencies and a shared ambition to develop the technology. The project is led by Nova Innovation (the coordinator), a world-leading tidal energy technology and project developer. Project partners are: ELSA, SKF, The University of Edinburgh, HMK, Wood Group, ORE Catapult, RSK Environnement and Mojo Maritime.

	Partner	Expertise
Tidal turbine supply, deployment and operation	**Nova Innovation**	A world leader in tidal turbine technology and project development. Full "water-to-wire" experience in turbine design, build, test, deployment and grid-connected, in-sea operation. Founded in 2010, in 2014 Nova installed the world's first community-owned tidal turbine and in 2016 they deployed two prototype, grid-connected Nova M100 turbines in the Bluemull Sound, Shetland, with a further device deployed in early 2017 – the world's first tidal energy array.
Provision of bearing and seal solutions for tidal turbines, including optimised programmes, condition monitoring systems and post-decommissioning forensic analysis	**SKF**	Leading worldwide supplier of solutions to maximise rotating equipment reliability and performance. Globally recognised expert in the simulation, delivery and analysis of bearing and seal solutions. Leading supplier of mechanical components and monitoring systems for onshore and offshore wind arrays. Have worked with Nova and other tidal energy companies for a number of years on developing bearing and sealing solutions for tidal turbines.
Tidal array modelling and design optimisation; tidal resource measurement and analysis; technology commercialisation	**The University of Edinburgh**	World leaders in ocean energy array design and modelling; electrical systems design; tidal resource measurement and analysis; interdisciplinary assessment, techno and socio-economic modelling of energy systems. Have worked with Nova for over three years on tidal array design and development.
Commercial expertise, independent verification of engineering projects and design	**Wood Group**	World leader in offshore technology and renewables. Wood Group has a global track record having assessed over 160GW of renewable energy developments internationally. Wood Group has decades of experience with expert engineering teams providing technical services, assessing and verifying renewable technologies and providing impartial proactive assessment of all project stages.
Mechanical and electrical drives and Power Electronic	**HMK**	HMK Automation & Drives is the Siemens Approved UK Industry Automation & Drive Technologies Partner, and the largest Integrated Drive Systems provider in the UK. Supplier of high-efficiency, high-availability, electrical and mechanical components and systems

Communication and dissemination, hydrodynamic modelling, marine energy expertise	**Offshore Renewable Energy (ORE) Catapult**	The UK's leading innovation centre for offshore renewable energy. Independent and trusted, with a unique combination of world-leading test and demonstration facilities and engineering and research expertise, ORE Catapult convenes the sector and delivers applied research, accelerating technology development, reducing risk and cost and enhancing UK-wide economic growth.
Renewable energy project development and operation	**ELSA**	Green Energy company based in Tournai (Belgium) and is part of the IDETA Group. It has a strong track record in community energy projects with interests in biomass, solar, wind, hydro-power, tidal and demand side infrastructure. Successful track record in tidal, partnering with Nova to deliver the Shetland Tidal Array Project
Environmental and socio-economic appraisal, consenting and community engagement	**RSK Environnment**	Multinational health, safety, environmental and socio-economic consultancy operating across the UK and Europe. The company was established in 1989 and now employs more than 1000 staff. RSK's key focus is the energy industry and they have worked on thousands of projects in this sphere. Their lead socio-economic impact assessor is based in their Paris office and her team operates to service clients across Europe.
Offshore operations planning and execution expertise for marine renewables	**Mojo Maritime**	Specialises in Project Management, Engineering and Consultancy services for the marine renewable energy industry, with a successful track record supporting high profile projects in offshore wind, wave and tidal energy. In addition, Mojo Maritime actively develops a range of products geared towards reducing the inherent risks and costs of working offshore.

4 Project overview

4.1 EnFAIT aim

The project's aim is to demonstrate a grid-connected tidal energy array that:

- demonstrates a step change in the lifetime cost of energy for tidal power;
- proves that high array reliability & availability is achievable with best practice maintenance regimes;
- captures and disseminates substantial learning on fundamental issues for the ocean energy industry;
- builds investor confidence;
- takes a huge step towards creating a commercial, bankable tidal energy sector; and
- at six turbines, will be the largest number of devices ever deployed in an ocean energy array.

4.2 EnFAIT objectives

The EnFAIT project will demonstrate a grid connected tidal energy array at a real-world tidal energy site, propelling tidal energy towards competing on a commercial basis with alternative renewable sources of energy generation. This project builds on the considerable body of work delivered by the project partners, including the successful deployment of three grid-connected prototype tidal turbines at the same site proposed for this project.

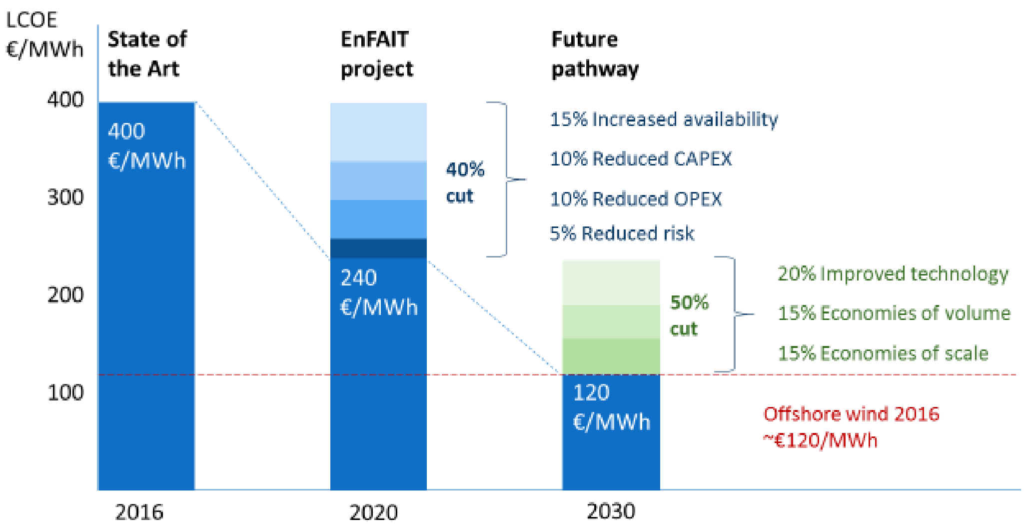

Figure 1 Impact of the EnFAIT project and future commercialisation on the LCOE of tidal arrays

Successful demonstration of the EnFAIT array will significantly increase the commercial viability of tidal power. Demonstrating significantly reduced lifetime cost of energy (LCOE) and mastery of risks at the project level will boost the confidence of potential clients and investors, giving European tidal energy developers a springboard into an emerging global market. In addition, this ground-breaking project will generate significant “learning by doing”, which will be disseminated to benefit the wider European ocean energy industry. This project is designed to generate common, fundamental learning that is not specific to one type or scale of technology, but is immediately applicable to the wider ocean energy sector. The project will showcase the positive impact of ocean energy on the natural environment and local community, highlighting the huge potential benefits of the sector for European industrial output and employment.

4.3 Project approach

In this first-of-kind project, three additional turbines will be deployed and demonstrated to create an array of six turbines at the Bluemull Sound site in Shetland. The existing three turbines deployed at the site will be incorporated within this project, allowing the delivery of real-world results from day one and build upon significant existing investment. The project is designed to generate common, fundamental learning for the wider ocean energy sector.

The EnFAIT project started in July 2017 and will run for 60 months (5 years), due to complete in June 2022.

4.4 The Shetland Tidal Array (STA)

The Nova M100 tidal turbines installed to date have a horizontal axis two-bladed rotor with a gearbox and medium voltage induction generator (Figure 2). The nacelle and rotor are mounted on top of a steel tripod substructure with additional concrete ballast. The whole assembly rests on the seabed under its own weight (no drilling is required) and each turbine is connected to a shoreside transformer by a subsea electrical cable.

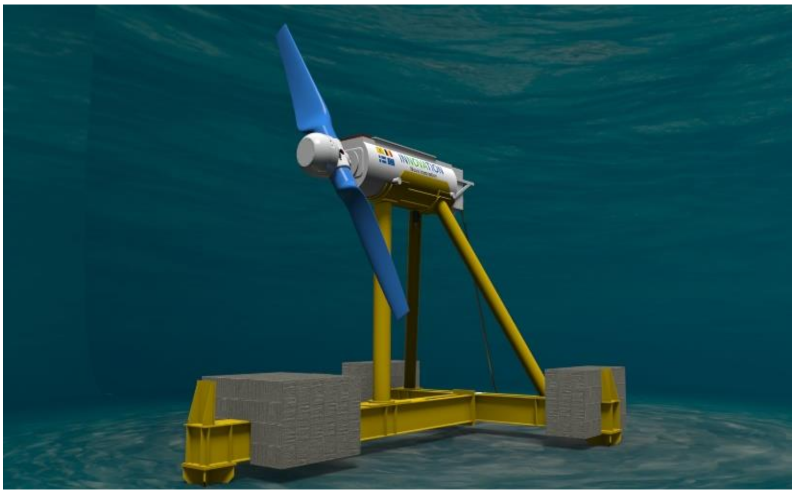

Figure 2: Nova M100 Basic Architecture

The Nova M100 tidal turbines installed to date have a horizontal axis two-bladed rotor with a gearbox and medium voltage induction generator (Figure 2). The nacelle and rotor are mounted on top of a steel tripod substructure with additional concrete ballast. The whole assembly rests on the seabed under its own weight (no drilling is required) and each turbine is connected to a shoreside transformer by a subsea electrical cable.

To give an idea of scale, the rotor diameter from tip to tip is 9m, the length of the nacelle is approx. 7m and the nacelle sits approx. 9m above the sea bed.

To date, three Nova M100 turbines have been installed and operated in Bluemull Sound, between the islands of Yell and Unst in Shetland (Figure 3).

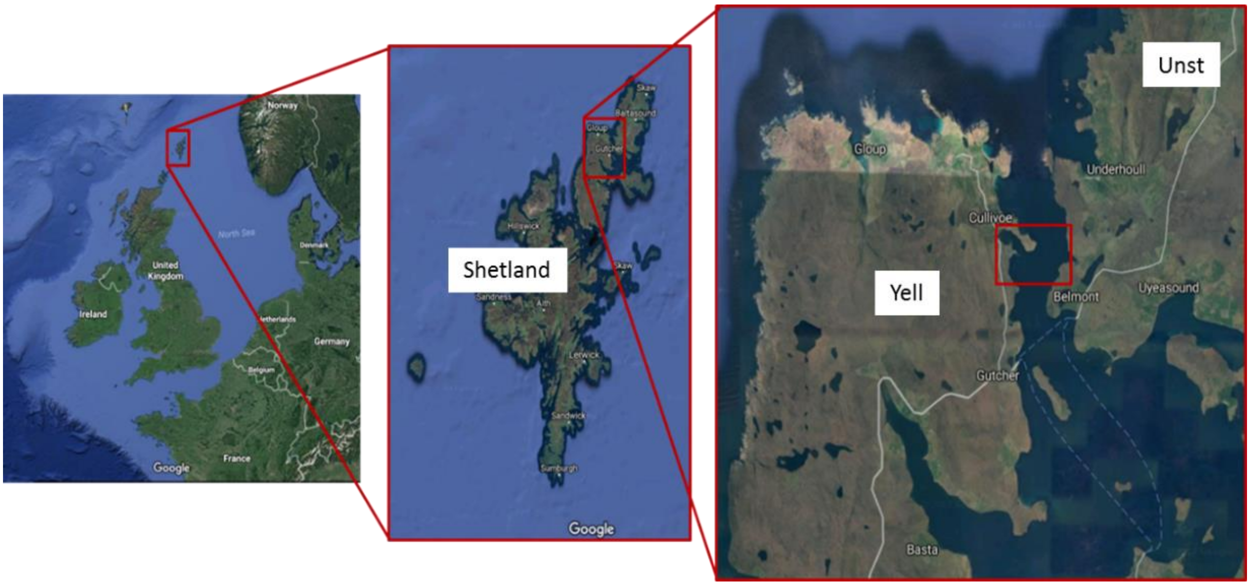

Figure 3: Bluemull Sound Location

Bluemull Sound is an excellent location for a tidal energy project, with characteristic maximum current speeds of 2.5m/s, good shelter from the prevailing wave and wind directions and a good quality pier at Cullivoe harbour on Yell, within one kilometre of where the turbines are deployed (Figure 4).

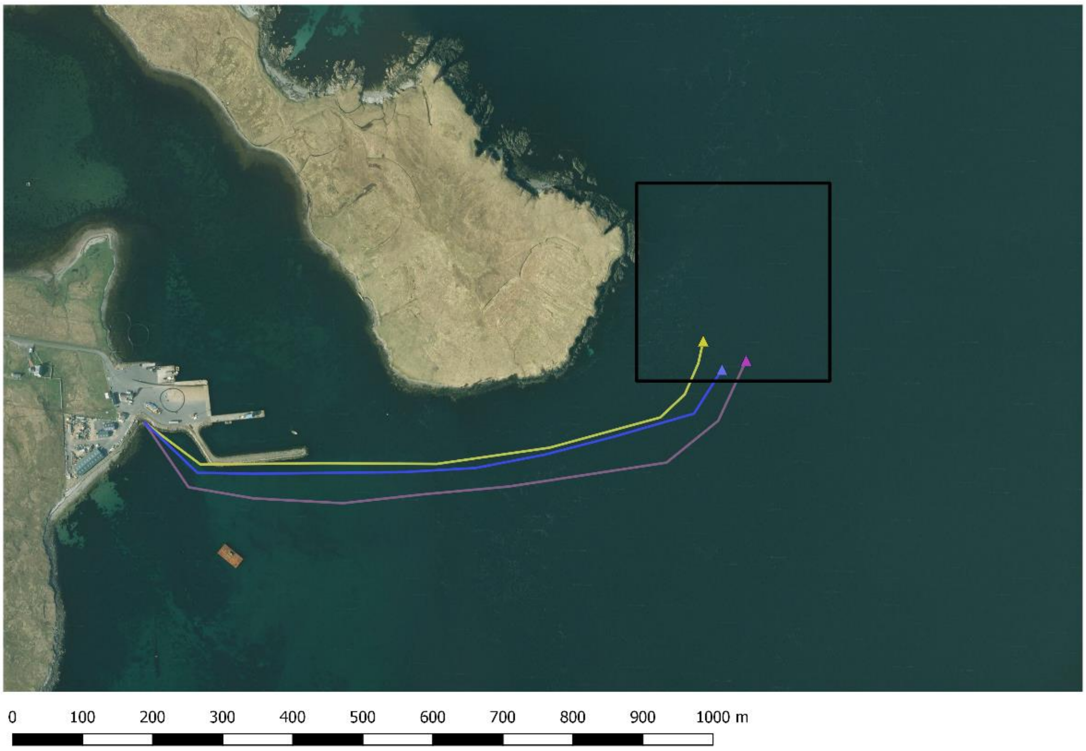

Figure 4: Shetland Tidal Array layout

Nova Innovation began operating this, the world's first fully operational and grid connected tidal energy array, in 2016. Since then the company has gained a wealth of operational experience.

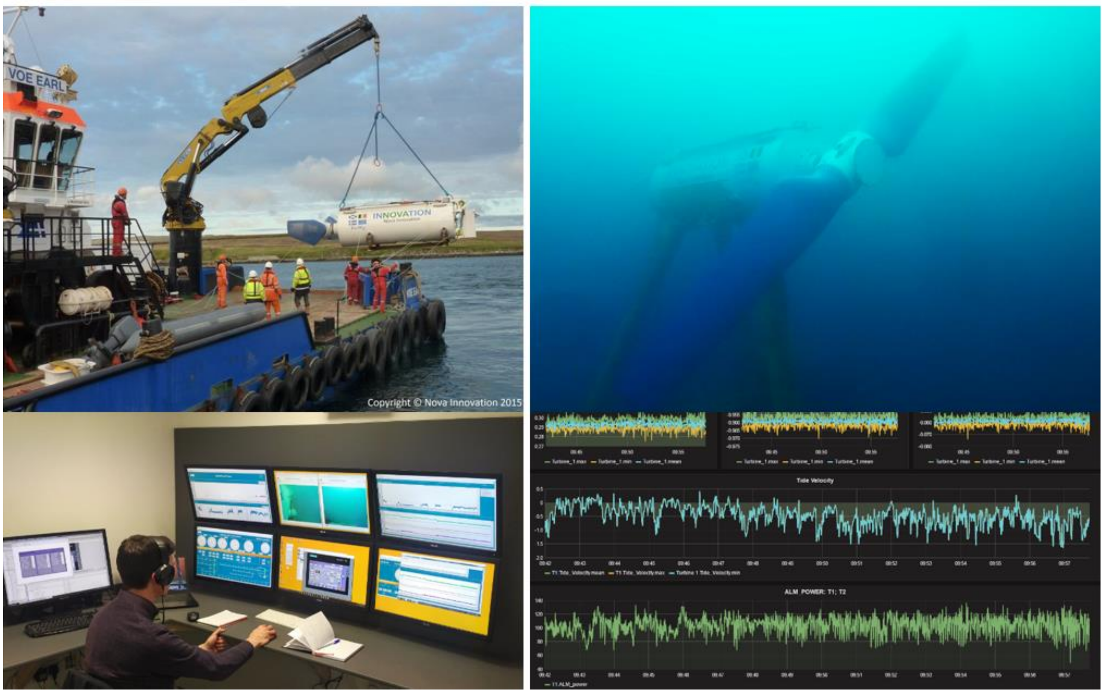

Figure 5: Shetland tidal array deployments, control centre and example data outputs

5 Test plan phases

5.1 Overview

The five year EnFAIT programme of tidal energy research, development and technology demonstration on the operational site in Bluemull Sound can be divided into the following phases of activity.

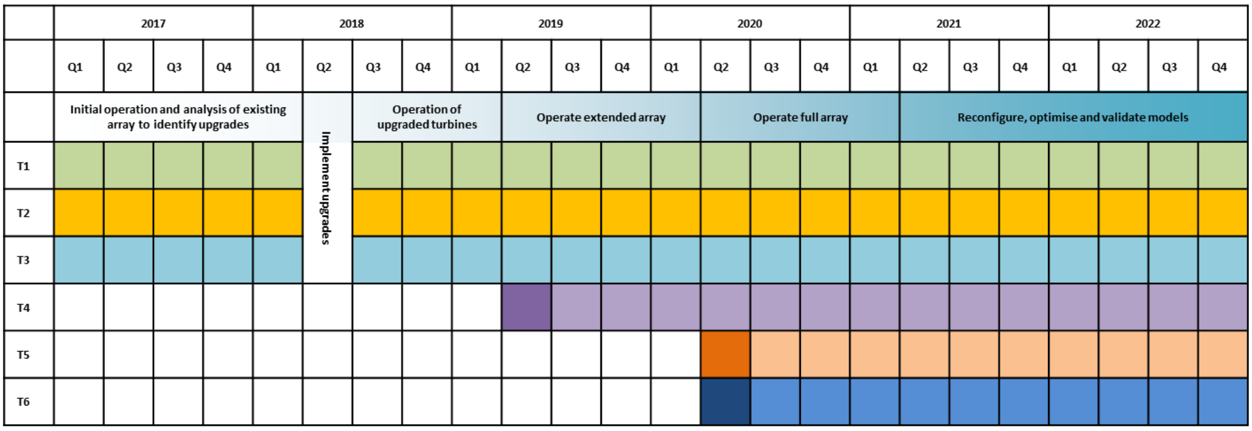

Figure 6: Overview of the 5-year EnFAIT programme

All of the project work packages link to the test activities in some way and these are shown in Figure 7.

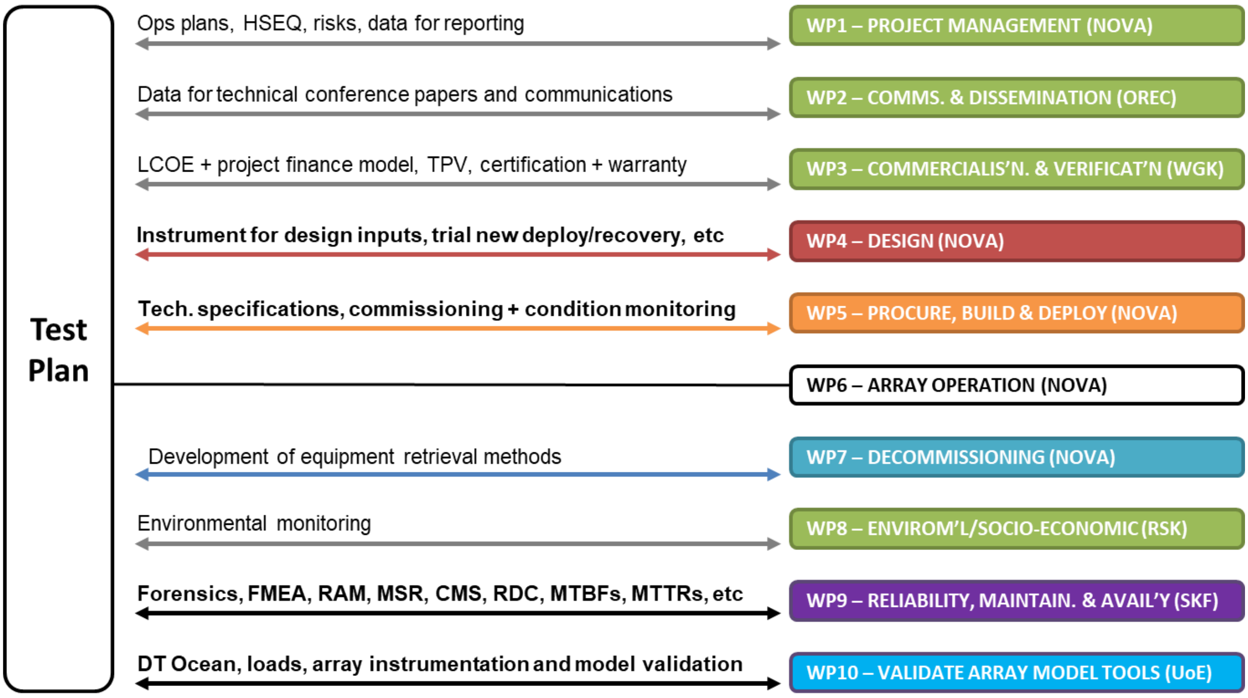

Figure 7: Test Plan links to EnFAIT work packages

5.2 Phase 1: Operation of the existing turbines

This initial phase is the operation, monitoring and analysis of the three existing Nova M100 turbines (T1–T3) with the aim of identifying suitable upgrades and additional instrumentation possibilities to maximise learning. This will take place from the start of the project in Q3 2017 through to Q1 2018.

Activities will collect operational data and report key performance indicators to provide a baseline for comparison with the improvements to be delivered later in the project. Activities will co-ordinate with the modelling tasks to ensure quality data are provided for resource assessment and turbine wake measurement purposes. It will provide information to the optimisation work package to inform the array spares strategy based on operational learning. One nacelle will be recovered and provide its drivetrain components to the optimisation work package for forensic analysis.

The aspects of measurement that may be considered include :

- Operations and maintenance requirements, with specific maintenance needs (both planned and unplanned);
- Detailed review of all consumed components;
- Develop full power curve for both ebb and flood operation; validate it; determine reduction to power curve when flow approaches at an offset angle;
- Measurement of eventual fluctuations from theoretical turbine power curve;
- As installed data: heading, verticality, positional tolerance for the substructure (and turbines respectively) to compare with expectation from micrositing;
- Cable movement at rear end of turbine to assess dynamics and requirements for improvement;
- Cable movement along length;
- USBL bucket on turbine / foundation as subsea positioning reference;
- Strain gauges on substructure and / or blades to compare design loads to actual loads and improve fatigue design;
- Test patterns with different anti-fouling coatings to assess efficiency of different manufacturer’s products going forward;
- Load shackles used to gather rigging tension data during the installation – confirm dynamic analysis and improve weather windows due to increased accuracy (and subsequent possible reduction in safety factors);
- Monitoring of anodes to confirm actuals against expected depletion and therefore requirement for intervention;
- Measure vibration on the nacelle for input into component design life calculation, and for analysis of common causes and cascading failures;
- Logbook of actual failures and comparison against original failure rates provided by components suppliers;
- Cost, procurement time and repair / replacement time of failed components;
- Detailed velocity field around the turbine;
- Detailed current profile in the lease area;
- Logbook of actual metocean conditions for historic installation / retrieval operations, to compare against modelled future operational limits, to help quantify time and cost improvements that can be expected from proposed design alterations; and
- Actual costs of operations and maintenance to compare with operations and maintenance assumptions in terms of impact on LCOE, to demonstrate the baseline for reductions in LCOE over the remaining lifetime of the project.

5.3 Phase 2: Operation of the three upgraded turbines

Following on from the upgrade of the original three turbines in Q2 2018, this phase will oversee operation of the three upgraded turbines (T1–T3) through to Q1 2019, with the priority of capturing learning that will inform the design, build and installation of a fourth turbine (T4).

The key activities are the installation and operation of the upgraded turbines T1-T3 at Bluemull Sound and to collect data from the new instrumentation. There will be continued recording and reporting of key performance indicators for the turbines and the array, and co-ordination with the modelling work package to ensure quality data are provided for wake modelling and performance assessment purposes, including the installation of any stand-alone instrument packages on the seabed. There will be recovery and redeployment of turbines for scheduled maintenance and in response to any unplanned issues. Learning will be captured from operational experiences which can be used to optimise the array design and layout.

The additional aspects of measurement that may be considered include :

- It is preferable to have the upgraded units fully stocked with sensors to learn as much as possible from the operations of the upgraded turbines. Appropriate sensors on critical components to monitor
    - Stresses;
    - Torques;
    - Acceleration / vibrations; and
    - Temperatures.
- Details of installation logistics;
- Different means of cathodic protection, for example anode banks; and
- Accelerated life testing of upgraded components in controlled environment and conditions.

5.4 Phase 3: Operation of the expanded array of four turbines

Following on from the build and commissioning of turbine T4, this phase will oversee operation of the expanded array of four turbines (T1–T4) from Q2 2019 to Q1 2020, with the priority to begin to evaluate upstream / downstream interactions.

Learning will be captured from T1 - T4 to allow any further improvements for T5-T7 to be implemented. There will be co-ordination with the modelling work package to ensure quality data are provided for load and performance assessment purposes.

The additional aspects of measurement that may be considered include :

- Data Buoys for monitoring tidal velocities : preferable to sea-bed mounted ADCPs due to easy means of re-location; potential to send live data via phone signal and/or radio;
- Methods of determining wake interactions;
- Turbulence analysis upstream / downstream and between turbines;
- Methods of determining impact on component fatigue life when considering turbine to turbine interactions;
- Maintain a movement activated camera to determine whether wake effects can mean that fish and other marine fauna find it more difficult to hold position;
- Use existing wake models to start at expected optimum distance; potential for additional tank testing beforehand; and
- Measure eventual variation in vibration due to the installation of T4.

5.5 Phase 4: Operation of the full array of six turbines

Following on from the build and commissioning of turbines T5 and T6, this phase will oversee operation of the full array of six turbines (T1–T6) with evaluation of the interaction and wake effects to be undertaken from Q2 2020 through to Q1 2021. In particular, the optimal inter-turbine spacing on the array spacing will be considered, in line with appropriate lease and consents arrangements.

There will be continued recording and reporting of key performance indicators for the turbines and the array, and co-ordination with the modelling work package to demonstrate the effect of operating upstream turbines on the loads and performance of those downstream.

The additional aspects of measurement that may be considered include :

- Lengthways spacing;
- Downstream spacing; and
- Row offset.

5.6 Phase 5: Optimisation of the full array and model validation

The full array (T1–T6) will be operated and optimised from Q2 2021 to Q2 2022, with options to move the substructures to alternative locations, and to demonstrate nacelle retrievals and deployments with a seventh “hot-swappable” nacelle (T7). This phase will also consider further instrumentation and modified operating regimes, with validation of assumptions made in the tidal array techno-economic modelling.

The array performance, load predictions and wake effects will be measured and provided to the modelling work package for comparison with predictions, with any change in key performance indicators monitored.

This phase of work aims to demonstrate improved turbine reliability and array availability through planned condition based maintenance, rather than unplanned reactive maintenance interventions and demonstrate rapid nacelle swap-out (e.g. T7 for T4) to validate availability assumptions. There will be trials to differ the intra-array control strategies to explore the impact on array energy production and the associated effect on loads and reliability.

The additional aspects of measurement that may be considered include :

- New velocity and turbulence measurements with new locations;
- Re-measure previous parameters;
- Concerted effort to align the resource work with array modelling and optimisation, so that a tool can be developed for future projects which takes resource data (in the required format) and then uses modelling to establish the fully optimum layout for any given site at a sufficiently early stage in the development process;
- Subsea Hub using wet mates and jumper cables for easy array manipulation, connection and disconnection;
- Intelligent tooling to simplify installation and retrieval;
- Potential to test the impact of deliberate improper alignment (as-installed heading, verticality) on load distribution, component fatigue and turbine efficiency; and
- Actual costs of operations and maintenance to be compared with operations and maintenance assumptions in terms of impact on LCOE, to demonstrate the reductions in LCOE achieved over the duration of the project.

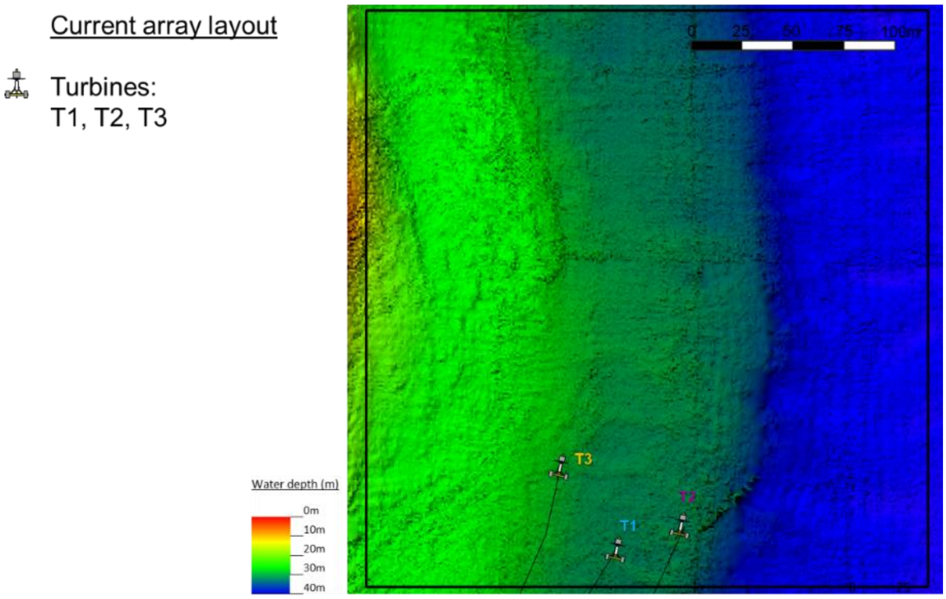

Figure 8: Layout of the Shetland Tidal Array as (August 2017)

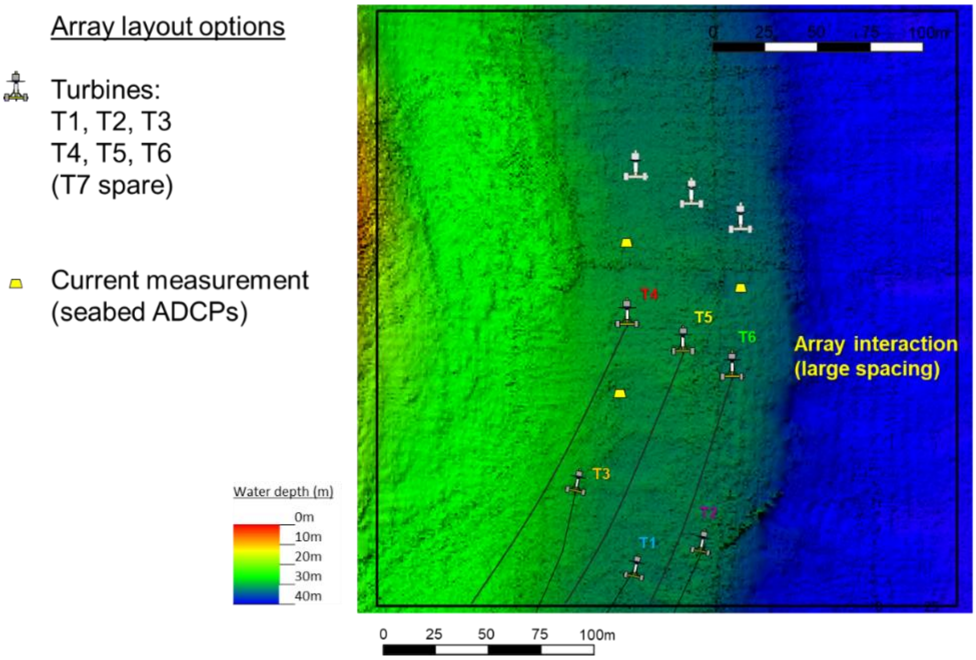

Figure 9: Possible layout of the full Shetland Tidal Array, to be in line with lease and consents arrangements

5.7 Phase 6: Resource measurement and site surveys

A campaign of detailed resource measurement and site surveys will be undertaken to gather quality data which will inform performance assessments, array optimisation work and environmental impact assessment.

The aspects of measurement that may be considered include :

- High Resolution Bathymetry: potentially also geotechnical, Cable Route survey, UXO Survey to ensure that device performance attributes can be compared to the seabed bathymetry and landscape topography;
- Seabed video of the new cable routes and of the locations for turbines;
- Tide: velocity, direction, turbulence on different relevant points throughout the site (working locations) based on time-series of historic / modelled data at as high a resolution as possible – ideally 5 minute intervals;
- Resource studies should include particular scrutiny of flow direction both over the tidal cycle, and shorter-term (at least 1Hz) in order that the effects of yaw misalignment on performance, loads and life can be fully understood. This information can then be fed into design requirements for future turbines;
- Measurement of velocity through the water column (magnitude and direction), measurement of turbulence intensity;
- Background noise studies, baselining before the array of turbines is in place;
- Environmental study, determine baseline so as to demonstrate any positive impact of turbines (e.g. reef effect);
- Wave: historic data (ideally 25 years) time-series of historic / modelled data with Hs, Hmax, direction, period at 3 hourly resolution (or finer);
- Wind: historic data (ideally 25 years) time-series of historic / modelled data at 3 hourly resolution, or finer.
- Tide: ideally live data feed to working vessel, choice between buoy and subsea frame;
- Wave: ideally live data feed from site (height, period, direction);
- Wave-tide interaction: number of ADCP deployments for high resolution ADCP / ADV measurements near seabed to inform cable stability modelling, at one or preferably multiple locations.

The main goal of this phase is to collect key data about the characteristics of the deployment site, devices and array plans in order to acquire the relevant input parameters to the DTOcean and AIM modelling tools to be used in the modelling work package (see Section 6.2). This will require a combination of numerical modelling, instrumentation design and purchase and deployment offshore, which will need to be co-ordinated with the turbine operations work package. Data will also be sourced from the historical Nova M100 turbine operations prior to the EnFAIT project, which will need to be collated and summarised for this purpose.

6 Key performance indicators and recording systems

6.1 Operations objectives

The main objectives of the operational activities of the EnFAIT project are to:

- Safely demonstrate an array of six turbines as part of a structured test programme;
- Demonstrate operational strategies to deliver the availability necessary for commercial arrays;
- Deliver load and performance data to validate tidal array design tools at full scale in the real world;
- Generate the results required to achieve third party verification of the operational results; and
- Capture and disseminate lessons learned for the industry on the optimised operation of tidal arrays.

6.2 Existing industry practice

The EnFAIT approach to recording array performance is informed by a number of different best practice guidance documents and initiatives from the industry and the sector, and will be developed further as the project progresses. Some of the approaches being considered are outlined in the following sections.

6.2.1 DTOcean

EnFAIT will apply the DTOcean (Design Tools for Ocean Energy) design tools in order to inform the design of the EnFAIT array, and to capture learning to inform future array designs. This will be carried out in the EnFAIT project by the University of Edinburgh. A technical array design study will include the generation of metrics as the start point for future comparison of design options.

The analysis of the array layout will be developed considering the interaction between devices and its impact to the overall resource as a key factor. Other important considerations include capital cost; cable stability; and array maintainability.

The optimal electrical system architecture will be determined, considering the specific requirements of the EnFAIT array. The cost and reliability implications of the electrical design linked to the array layout will also be studied.

Analysis of the turbine substructures will be conducted in order to understand the impact on operations and lifetime costs.

Logistics aspects require links with the rest of the DTOcean activities. Deployment and installation methods will be analysed to develop solutions for efficient and safe array development and operations.

The adaptation and development of existing knowledge in system control and maintenance developed in offshore wind will be applied to ocean energy arrays.

Metric outputs for the array will be compared with actual data collected from the array. Predictions and technical metrics obtained in the initial phases of EnFAIT will be compared with actual array data. A comparison between the expected and measured LCOE will be performed. The resource prospects may be analysed with respect to the actual array metrics for operations and maintenance.

The experience from applying the tools to a real-world tidal project will be collected to allow the DTOcean array design tools to be adapted and refined in light of experience, and learning from this work will be captured for dissemination to the wider industry.

6.2.2 AIM

Array Interaction Modelling (AIM) measures the impact of array wake interactions on turbine loads and compares them to the output of state of the art modelling tools. This will be carried out in the EnFAIT project by ORE Catapult.

A sensor system will be designed to characterise the tidal flow around multiple operational array layout configurations, including turbine mounted, seabed mounted and boat mounted instruments. A complementary sensor system will be designed to measure relevant load data from multiple tidal turbines. Liaison will take place with industry stakeholders (including equipment suppliers, offshore survey companies, academics and tidal device developers) to inform these designs.

State of the art knowledge about turbine wake interactions and turbine load modelling tools will be utilised to predict the impact of the proposed array layouts on turbine fatigue and extreme loads.

Sensor systems will be deployed in the array to collect data for processing. Results will be analysed and compared to the predictions made with measured data. There will be coordination with the array operational team to ensure the array is operated in a way to obtain maximum benefit from the array instrumentation.

Instrumentation layout and outputs will be designed, using feedback from the early deployments and then deployed in the array. The sensors will be moved and redeployed around differing array configurations, with data collected, processed, analysed and reported.

The results obtained will be translated into exploitation work and dissemination papers and outputs, with training workshops planned and executed.

6.2.3 Mermaid

Mermaid (Marine Economic Risk Management Aid) is a sophisticated marine project optimisation system designed to enable huge operational cost-savings for a huge variety of marine operations, launched by Mojo Maritime, now part of James Fisher and Sons plc.

Mermaid gives companies involved in marine operations increased understanding of the impact of weather and tidal forces on a project's schedule. By accurately simulating marine operations against historical weather and tidal data, Mermaid enables enhanced decision-making in the early planning stages to support significant cost-savings through project optimisation.

Mermaid allows users to realistically simulate marine operations to uncover risks and critical operations prior to going offshore, enabling enhanced decision-making in the early planning stages which can be critical to the success and cost-effectiveness of an operation.

Mermaid already has a proven track record of success having been deployed on a number of projects for high-profile clients in the offshore wind, wave and tidal sectors. The system was used to analyse cable-laying methods for offshore wind farms to determine the preferred method for cable storage and deployment and the vessel spread required to minimise cost, duration and risk. It has also demonstrated when it's possible to perform certain operations in marginal weather (where critical tasks had formerly been suspended) with minimal risk.

6.2.4 SPARTA (System Performance, Availability and Reliability Trend Analysis)

SPARTA is a major data sharing and collaboration programme for offshore wind farm operators, which is co-sponsored by EnFAIT project partner ORE Catapult with The Crown Estate. It aims to benchmark wind turbine operational performance and drive down the lifetime cost of offshore wind energy by increasing reliability and availability. As part of the SPARTA project, performance metrics were derived from the RDS-PP (Nordic) systematic plant designation system for a wind turbine, for use within the SPARTA programme. This set of reporting metrics provides a uniform and agreed way of benchmarking windfarm operations and maintenance and cover a range of performance measures including: repairs, turbine availability, cable and grid outages, and heavy-lifting vessel usage.

ORE Catapult also operates WEBS (Wind Energy Benchmarking Services), which is a secure platform to benchmark wind farm availability, performance, reliability and costs providing a comprehensive set of trending data to gain insight and drive operational improvement.

The EnFAIT project will work closely with ORE Catapult to consider how the metrics used within SPARTA and WEBS could be of most benefit to the tidal energy sector, in terms of referential inputs and benchmarking outputs to allow performance comparisons to be made between the turbines on the Shetland Tidal Array.

6.2.5 Assessment of Performance of Tidal Energy Conversion Systems (EMEC, 2009)

This EMEC standard establishes a uniform methodology to ensure consistency and accuracy in the measurement and analysis of the power performance exhibited by tidal energy conversion systems (TECS). This document also provides guidance in the measurement, analysis and reporting of the performance testing of TECS.

6.2.6 Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems (EMEC, 2009)

This guide promotes the development of a successful energy generation industry based on the widespread manufacture and deployment of reliable marine energy converters. The guide is flexible, in that it does not prescribe a set way of doing things, but outlines a range of techniques that can be used and considered.

The guidance is goal-based, in that it takes as its starting point the definitions of the reliability, maintainability and survivability requirements for a successful and economic energy farm and applies these requirements to the individual converter and suggests tools and techniques to help meet these requirements.

It focuses on three areas that are of fundamental importance to the success of a marine energy conversion system; which should be considered at all stages from concept to production. These are:

- Reliability, and in particular the trade-offs between component reliability and system redundancy to achieve the required availability;
- Maintainability, and in particular the methods of, and access for, preventive and corrective maintenance; and
- Survivability, and in particular the opportunities for avoiding extreme loadings and conditions.

Further detail can be found in Appendix 1.

6.2.7 IEC Technical Committee (TC) 114 Marine energy – Wave, tidal and other water current converters

The International Electrotechnical Commission produces international standards and conformity assessments for all electrical, electronic and related technologies. The scope of the IEC Technical Committee (TC) 114 Marine energy - Wave, tidal and other water current converters is as follows:

- To prepare international standards for marine energy conversion systems. The primary focus will be on conversion of wave, tidal and other water current energy into electrical energy, although other conversion methods, systems and products are included. Tidal barrage and dam installations, as covered by TC 4, are excluded.

The standards produced by TC 114 will address:

- system definitions;
- management plan for technology and project development;
- performance measurements of wave, tidal and water current energy converters;
- resource assessment requirements;
- design and safety including reliability and survivability;
- deployment, operation, maintenance and retrieval;
- commissioning and decommissioning;
- electrical interface, including array integration and / or grid integration;
- testing: laboratory, manufacturing and factory acceptance; and
- measurement methodologies of physical parameters of the device.

6.2.8 IEC TS 61400-26-1:2011 Wind turbines – Part 26-1: Time-based availability for wind turbine generating systems

IEC TS 61400-26-1:2011(E) defines generic information categories to which fractions of time can be assigned for a wind turbine generating system (WTGS) considering internal and external conditions based on fraction of time and specifying the following:

- generic information categories of a WTGS considering availability and other performance indicators;
- information category priority in order to discriminate between concurrent categories;
- entry and exit point for each information category in order to allocate designation of time; and
- informative annexes providing various examples.

6.2.9 IEC TS 61400-26-2:2014 Wind turbines – Part 26-1: Production-based availability for wind turbine generating systems

IEC TS 61400-26-2:2014 provides a framework from which production-based performance indicators of a wind turbine generator system can be derived. It unambiguously describes how data is categorised and provides examples of how the data can be used to derive performance indicators. The approach of this part of IEC 61400 is to expand the time allocation model, introduced in IEC TS 61400-26-1, with two additional layers for recording of the actual energy production and potential energy production associated with the concurrent time allocation. This document also includes informative annexes with examples of :

- determination of lost production;
- algorithms for production-based indicators;
- other performance indicators; and
- application scenarios.

6.3 Approach for EnFAIT

Over the course of the EnFAIT project, a systematic approach to the collection, quality assurance, reporting and analysis of data will be developed which will include:

- Continuous monitoring and logging of key performance and operational parameters;

- Automatic reporting of key performance indicators;
- Production of statistics for each metric: mean, max, min, standard deviation, P10, P25, P50, P75, P90;
- Robust analysis of lagging indicators (e.g. capacity factor) to identify dependencies and how these can be improved;
- Develop leading rather than lagging indicators where possible (e.g. Mean Time to Successful Nacelle Recovery) to reveal how specific systems or functional areas are performing;
- Ongoing review of the value of each metric, to evaluate their usefulness to project parters and whether these metrics are aligned with existing processes;
- Include commercial factors such as framework agreements for vessels, insurance premiums, day rate vs. fixed price for contracts; and
- Alignment of metrics with existing industry best practice.

Appendix I Excerpts from EMEC Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems (EMEC, 2009)

This EMEC standard highlights the following factors that should be considered when designing for reliability, maintainability and survivability:

CapEx

- the design of the equipment
- the supply chain for the equipment
- the installation of the equipment

Revenue

- the environment in which the converter can be installed and operated
- the energy generated by the converters and hence the revenue to the project

OpEx

- the amount of maintenance required
- the cost of maintenance of the converters

RiskEx

- the ability to raise investment and the cost of the investment
- the ability to insure and certify and the cost of insurance
- the effect on the asset/safety/environment of failure and the cost to rectify
- warranty costs.

TECHNICAL FACTORS	
Energy farm configuration	Number of converters
	Location of converters
	Number of offshore sub-stations
	Offshore cable architecture (inter-array and export cables)
	Onshore cable architecture to grid connection point
Converter reliability	Failure rate of equipment and systems
	Effect of failure on generation
	Required repair action
Maintenance and repair policy	Balance between preventive, corrective and on-condition maintenance
	Maintenance task frequency
	Maintenance task duration
	Access to converter for maintenance
	Required resources for maintenance

OPERATIONAL FACTORS	
Accessibility	Necessary metocean conditions for installation and for maintenance
Ability to work on converters	Method for getting staff to and from the converter
	Method for getting staff on and off the converter
	Methods for staff to safely and effectively work on the converter
Ability to remove the converter	Method of disconnecting the converter
	Method for taking the converter off-station
	Methods for working on the converter off-station
	Method for putting the converter back on station
	Method for re-connecting the converter
Metocean conditions	Wind speed and direction
	Wave height, period and direction
	Tidal current velocity
	Tidal periods
	Water depth
	Daylight and visibility
	Sea ice
	Threat of storms
Environmental conditions	Temperature
	Rain
	Lightning
Ability to generate during failures or maintenance	Ability to defer failures by reducing operating conditions to slack or calm water
	Ability to defer maintenance to slack or calm water
	Duration of slack water for maintenance
	Duration of calm water for maintenance
Marine resources required	The types and numbers of vessels required
	The location of the vessels
	The transit times from shore bases
	The capability of the vessels
	The availability of relevant personnel with appropriate expertise

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