Client: Sustainable Energy Authority of Ireland

Appendix 2 Technology Readiness Levels for Supply Chain Study for WestWave

ESBIoe-WAV-11-027

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Wave Power Conversion Systems: ESBI Technology Readiness Definition – Generic Summary Level

Notes: More specific verification requirements should be derived for particular wave power conversion technologies.
Where mentioned, "scale" refers to a physical Froude scaling of wave heights, periods and device dimensions relative to commercial product.

ESBI TRL 1: Configuration described

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Basic principles observed and reported **System Definition:** • Oscillator(s) with wave absorbing hydrodynamic interface identified • Oscillator(s) with acceptable / controllable mechanical impedance identified • Reacting bodies / PTO opportunity identified • Relevant physical processes identified • Station-keeping/foundation opportunity identified	**Purpose(s) of technology identified** **Market:** Electricity generation, water desalination, pumping, ec.	**Consistent with ESBI Requirements:** ☐ Concept sketch with annotations and device description. ☐ Uses of the technology identified.	**Spend:** Negligible **Power Revenue:** None **Funding:** None **Duration:** 2-14 days **Team:** Inventor

ESBI TRL 2: Technology Development Stream Initiated

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology concept and/or application formulated. **System Definition:** Principal dimensions and main components identified. Target water depth and wave resource requirements identified. Basic geotechnical requirements identified. Scope of system and external interfaces defined. **Performance/Costs:** Simple calculations and read across from existing data to estimate power production performance and size of major structural elements. **Mechanical Integrity:** Configuration consistent with survivability for the target ocean environment.	**Market Identified** **Site Identification:** Suitable sites identified for large scale mobilisation of technology. **Lifecycle considerations:** The concept configuration should include consideration of manufacturability, deployability, access for maintenance, operability and decommissioning. Health and safety hazards should be identified and designed out where possible. **Customer Interface:** Point of sale of product and interface with customer is defined. (e.g. national grid connection point, etc)	**Consistent with ESBI Requirements:** ☐ Concept configuration drawing ☐ Concept report defining system layout, function, site requirements and appreciation of lifecycle implications. ☐ Performance and cost calculations /estimates indicating realistic targets. ☐ Device configuration and sizing consistent with offshore experience.	**Spend:** €10-50k **Power Revenue:** None **Funding:** None **Duration:** 2-3 months **Team:** Inventor

ESBI TRL 3: Initial Product Verification - 1:100 to 1:25 scale laboratory testing

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Analytical and experimental critical function and/or characteristic proof-of-concept. **HMRC Development and Evaluation Protocol PHASE 1** **Performance:** Experimental Ocean Basin Laboratory testing at 1:25 – 1:100. Absorbed power measured in monochromatic and synthesised irregular sea states (as per HMRC D&E.P). **Performance:** Numerical simulation model in time domain – inviscid hydrodynamics, rigid body motions and idealised control forces to predict power absorbed by device. **Survival:** Moorings Analytical Simulation Model: Representative survival events to predict design wave response and define initial mooring sizing and induced loads. **Survival:** Experimental Ocean Basin Laboratory Testing at 1:100 scale or greater with qualitative assessment of survival aspects: acceptable mooring loads, sea-keeping, greenwater, slamming, etc. **System Definition:** Principal dimensions and inertial information, ensuring static stability, acceptable dynamic behaviour, etc. PTO degree of freedom defined (eg as linear PTO including stroke and peak force requirements, air turbine including peak volume flows and damping coefficients)	**Initial capital cost and power production estimates / targets established** **Site Identification:** Wave Resource measured / analysed for target market sites. Indicative resource scatter plots obtained and justified. Consistent water depth and seabed geology should be considered. **Cost Estimates / Targets:** Based on critical dimensions and tonnage, an initial cost breakdown / commercial cost targets with documented justification for capital expenditure. **Energy Production Estimates / Targets:** Use of power matrix to predict energy production. Allowances/targets for converting absorbed power to product should be established.	**Consistent with ESBI Requirements:** ☐ Power Matrix based on measured absorbed power for representative control forces at 1:25 to 1:100 scale or greater. ☐ Numerical simulation model for rigid body oscillator with simple representative control methods. ☐ Verification report comparing measured characteristics and numerical predictions. Physical and numerical modelling assumptions are presented. Comments on validity of energy production modelling methods are given. ☐ Report(s) showing cost targets for commercial capital expenditure, justified by realistic structural weight and material costs.	**Spend:** €0.5m **Power Revenue:** None **Funding Mix:** Govt Research Grants & Company founder investments. **Duration:** 6-9 months **Team:** 1-2 staff plus experimental and simulation Support

ESBI TRL 4: Laboratory and Analytical Verification – 1:25 scale or larger laboratory testing

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology component and/or basic technology subsystem validation in a laboratory environment. **HMRC Development and Evaluation Protocol PHASE 2** **Control and Performance:** 1:25 scale or greater experimental ocean basin activity including control forces representative of actual PTO capability. Absorbed power measured for representative control force behaviour. **Survivability:** End-stop control (if relevant): Survival condition defined and tested at 1:25 scale or greater. (e.g. ballasting, detuning oscillator, "locked" PTO loads, etc) **Survivability:** Moorings. As representative a mooring system as possible should be used during 1:25 (or greater) scale physical modelling. Simulation verification and where tank capability permits this should be verified experimentally in representative storm waves. **Naval Architecture:** Basic assessment showing that marine standards can be met and manufacturability achievable. **PTO / Operational end-stop control:** Full scale PTO defined. Scaled laboratory bench-testing of simplified but representative PTO in conjunction with use of simulation to extrapolate to full scale behaviour – control force capability and mechanical conversion efficiency analysed by a combination of scaled experiment and simulation. **Electrical Powertrain / Power Export:** The means of converting mechanical power for export and the transmission of this power to market should be defined. Calculations / basic simulations of export efficiencies complete. **System Definition (commercial):** System breakdown and high level definition of subsystems: e.g. Collector Subsystem, Mechanical PTO System, Electrical Conversion System, Power Export System, Position Mooring System requirements established. Major internal interfaces identified between subsystems as well as clarity of system level external interface (e.g. grid code compliance requirements, marine navigation).	**Preliminary Lifecycle design** **Health & Safety:** Risk assessment (HAZID) projected for all phases of technology in-service lifecycle. Design change process implemented to minimise or eliminate risk wherever possible. (e.g. eliminate offshore intervention, offshore crew transfers, diver operations, working at height, etc) **Manufacturability:** Naval architecture / Shipyard input: Storyboard for manufacture and assembly of full-scale system, based on one or more existing manufacturing facilities. Design change process implemented to enable manufacturability (e.g. reduce crane requirements, facilitate welding operations, avoid complex steel forming, etc.) **Deployability:** Storyboard of operations required to install and commission full scale technology at target site based on available vessels and facilities. **Operability:** Requirements for telemetry and SCADA system for remote supervisory control of system. Instrumentation requirements identified. **Maintainability:** Components categorised by life / level of maintenance required. Decisions on maintenance strategy: intervals and decision to maintain on-site or disconnect and tow to shore. **Reliability:** Qualitative FMEA at system level. Design change for reliability wherever potential problems emerge. **Array Layout:** Array spatial assessment for target site integrating multiple systems, allowing for mooring system footprint, power export system and estimate of resource affected area. **Economic Viability:** Business model developed for small array using updated CAPEX and OPEX targets and justification. Energy production estimated using updated knowledge including conversion and export efficiencies.	**Consistent with ESBI Requirements:** ☐ Power Matrix based on measured absorbed power for representative control forces at 1:25 scale or greater. ☐ Control strategy shown to protect operational system from end stop events, in irregular waves. ☐ Survival mode measured mooring / foundation / interface loads matching survival simulation predictions. ☐ Scaled and simplified experimental PTO results validating simulation of the same system. (hydraulic, turbine, etc) ☐ Use of validated PTO simulation to extrapolate conversion efficiencies to full scale system in irregular waves. ☐ For baseline converter system, all subsystem requirements defined and interfaces identified. ☐ Schematic of power export system up to point of system external interface based on a small array of devices. ☐ SCADA, control and instrumentation requirements defined. ☐ Health & Safety Risk assessment ☐ High level Maintenance plan ☐ System Level FMEA, inspection and redundancy strategy. ☐ Array schematic for sample commercial site & consistent moorings. ☐ Business model for commercial array project based on latest CAPEX, OPEX and Power production estimates.	**Spend:** €0.5 – 1.0m **Power Revenue:** None **Funding Mix:** Govt Research Grants & Angel Investors. Less likely from some small strategic investment (VC, utility, system integrator) **Duration:** 9-12 months **Team:** 4-8 staff plus experimental and simulation Support. Plans underway to bring capability into team.

ESBI TRL 5: Reduced Risk Subsystem Verification - 1:15 to 1:4 scale subsystems tested in a laboratory or fetch-limited site.

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology component and/or basic technology <u>subsystem</u> validation in a relevant environment. **HMRC Development and Evaluation PHASE 3 (Lab Tests / fetch-limited site)** **Absorber:** *Performance:* Experimental verification of 1:4-1:15 scale (or larger) moored structure in large basin facility or benign site. Measurement of dynamic response to operational sea-state excitation. Conservative control methods may be employed at this stage. Measured response behaviour compared to expectations from numerical simulation for validation. Validated simulation used to extrapolate performance to full-scale with fully operational control. *Survivability:* Experimental 1:4-1:15 scale (or larger) moored structure exposed to scaled storm events in the sea. Mooring forces measured and compared to numerical model predictions. **PTO / End-stop control:** Experimental verification of PTO system at 1:4 (or larger) Froude scale power levels in laboratory environment (or within scaled sea-trial oscillator). **Power Export:** Experimental verification at 1:4 scale or larger of any unconventional components. (e.g. mechanical integrity of electrical risers in large waves/shallow water, marinised electrical substations, 11kV wet mate connectors) **Naval Architecture:** Static and Dynamic stability and other naval architecture concerns are addressed. Early structural layouts for commercial scale complete. Detail designs for TRL 6 scale structure. **Operability / SCADA:** SCADA and telemetry developed to support large scale experiments control and data acquisition. **System Definition (commercial):** System and interface definition for commercial scale system is further detailed and updated with supplier feedback and test information. **System Definition (next phase):** Full detail design definition for 1:4 (or larger) scale system and subsystems suitable for procurement exercise for TRL 6 testing. Experimental schedule for TRL 6 testing drafted.	**Supply-chain Mobilisation** Major Subsystem Integrators consulted and actively working on meeting subsystem requirements **Health & Safety:** Risk Assessments (HAZOP / HAZID) complete for all phases of scaled sea / lake / basin trial activity. Design/Process changes implemented to eliminate identified risks. Event Log in place to catch arising risks and hazardous events. Impacts on commercial product considered. **Health & Safety / Insurability:** In respect of sea / lake trials, inspections and reports by a marine surveyor / classification society should be used to obtain all insurance deemed necessary. **Interface Management:** Supply chain feedback and interaction used to define important interfaces and to iterate the system level definition. **Maintainability / Deployability (commercial):** Intervention and deployment operations described. Warranty Surveyors assessment of planned marine operations is available. **Manufacturability (commercial):** Consultation with potential suppliers on fabrication and assembly at commercial scale. Design update as required. **Manufacturability (next phase):** Structural design, fabrication, assembly and fit-out of TRL 6 structure at advanced stage of planning with suppliers consulted. **Deployability (next phase):** TRL 6 Installation & Removal Operations of foundation, mooring systems and device from quayside to experimental site are defined. **Economic Viability:** Updated business model using supplier derived cost estimates and where possible, quotations.	**Consistent with ESBI Requirements:** ☐ Simulation predictions of device motion shown to match measured response of structure in basin / sea. ☐ PTO conversion simulation and large scale experimental testing indicating that the required conversion efficiency can be achieved for power flows associated with irregular waves. ☐ Updated power matrix based on validated simulation & PTO conversion efficiencies. ☐ Scaled storm survival and acceptable mooring loads. Measurements consistent with simulation predictions. ☐ SCADA for remote control of an offshore system developed. ☐ Health & Safety HAZID / HAZOP reports and effected design changes. Event log procedure in place. ☐ Marine surveyors consulted for large scale experimental work. Appropriate insurance obtained for activity. ☐ Warranty surveyor assessment of proposed deployment and intervention marine operations. ☐ Commercial system definition updated with supplier derived data. ☐ TRL 6 hardware system definition, experimental plan, fabricators and marine operations suppliers in place. ☐ Commercial business model updated with converted energy production and supplier derived cost estimates.	**Spend:** €3-5m **Power Revenue:** None **Funding Mix:** Govt Research Grants. Strategic investment (VC, utility, system integrator) **Duration:** 12-18 months **Team:** 10-15 staff covering simulation, control, structural, electrical design & definition, commercial & procurement. Plus subcontract support & steel fabrication.
ESBI Technology Partnership Readiness Level 1 Achieved			

ESBI TRL 6: Reduced-Risk full System Verification - 1:4 scale or larger in a limited fetch sea trial.

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology <u>system</u> model or prototype demonstration in a relevant environment. **HMRC Development and Evaluation PHASE 3 (Sea Trials)** Representative (1:4 scale or larger) full system (excl power export) deployed and operating at a sea test site. **PTO / End-stop control:** Experimental PTO system deployed should be as required to test aspects of control and absorbed power. Heavily instrumented 1:4 Froude scale power output (or larger) operating within the system at sea to produce electricity. Electricity need not be exported. **Performance:** Experimental Sea Trials of technology configuration in scaled wave resources (1:4 scale or larger – e.g. Galway Bay). Based upon electrical power at the device terminals (pre-export), verification of a range of operating conditions in the power matrix should be carried out. The deviation from idealised simulation predictions due to relevant environmental phenomena should be established. **Power Quality:** Simulations of generator and power export system, supported by experimental mechanical (e.g. shaft) and electrical power measurements in the relevant environment. Results showing that grid code compliance (e.g. IEC 61000, IEC61400-21, etc) is achievable. **Survivability:** Site should be selected so that the 1:1 year return period storm is similar to or more severe than a scaled 1:100 year return period storm at commercial scale. The test mooring subsystem should be representative of commercial intent and certifiable. Survival mode features (e.g. detuning) should be tested. Measurements taken for model validation. **Marine Environment:** The effect of marine environment on the device growth and corrosion protection systems to be considered. Learning applied to commercial definition. **System Definition (commercial):** System and interface definition for commercial scale system is further detailed and updated with customer/supplier feedback and test information. **System Definition (next phase TRL7):** Low level requirements definition of commercial scale system and all subsystems, sufficient to enable detail design exercise to commence. Marine Operations storyboard and requirements document. Experimental schedule for TRL 7 testing drafted.	**Customer interaction** Discussions with potential owner-operators of technology to establish project requirements. **Health & Safety:** Risk Assessments (HAZOP / HAZID) complete for all phases of sea-trial activity. Design/Process changes implemented to eliminate identified risk. Event Log in place to catch arising risks and hazardous events. Impacts on commercial product considered. **Health & Safety / Insurability:** In respect of sea trials, inspections and reports by a marine surveyor / classification society should be used to obtain all insurance deemed necessary. **Reliability:** Detailed FMEA to sub-system levels including supplier input on major subsystems. **Failure / Issue reporting System:** Failure & Issue reporting system in place for duration of the deployment to record all operational faults and issues that arise. FMEA, design/process change enacted to reflect arising issues. **Operations & Maintenance:** Supervisory control of the device from shore should be demonstrated. Operations plan and lifecycle maintenance and intervention schedule for typical commercial project is supported by potential O&M suppliers. Customer buy-in that O&M plan meets their requirements. **Manufacturability:** Advanced plans for supply of TRL7 subsystems, fabrication and assembly. Supplier quotations / cost estimates available. **Deployability:** Advanced plans for one-off deployments with a view to validating commercial intentions. (geotechnics, vessel,etc) **Economic Viability:** Updated economic model based upon customer requirements for early projects. Use of supplier derived costs and where possible, quotations. OPEX cost including supplier derived information for marine operations & vessel hire should be included.	**Consistent with ESBI Requirements:** ☐ Power matrix based on measure of absorbed power in the relevant environment at 1:4 scale or larger. ☐ Commercial Power matrix extrapolated through simulation of converted power at grid connection point. (verified by 1:4 scale experiments) ☐ Electrical system simulation demonstrates grid compliant power using measured electrical power as an input. ☐ Health & Safety HAZID / HAZOP reports and effected design changes. Event log procedure, acceptable insurance and certification in place. ☐ Mooring and structural integrity demonstrated in maximum operating conditions and storm survival conditions. ☐ Detailed FMEA and failure reporting system in place. Marine environment effects logged and appropriate design / process change action taken. ☐ Updated commercial system definition. O&M plan formulated in detail by suppliers. Customer vetting of O&M. ☐ TRL 7 detailed system definition complete. Hardware suppliers identified. ☐ TRL 7 installation operations detailed with a view to validating commercial intentions. ☐ Customer agreed commercial project economic model. CAPEX/OPEX costs consistent with supply chain indications. Energy production consistent.	**Spend:** €5m **Power Revenue:** None **Funding Mix:** Govt Research Grants. Strategic investment (VC, utility, system integrator) **Duration:** 12-18 months **Team:** 15-20 staff covering simulation & control, structural, electrical design & definition, commercial & procurement. Plus subcontract support & steel fabrication.

ESBI Technology Partnership Readiness Level 2 Achieved

ESBI TRL 7 – Ocean Operational Readiness – 1:2 scale (or larger) in an open ocean environment

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology <u>system</u> prototype demonstration in an operational environment. **HMRC Development and Evaluation Protocol PHASE 4** Representative (1:2 scale or larger) end-to-end system deployed and operating grid-connected at an ocean test site (EMEC or similar). **Operability:** Initial conservative operational restrictions in place as necessary. Conservative control methods slowly relaxed with operational experience. Validation of some power matrix points based on commercial control methods. **Performance:** Comparisons of measured power with predictions from simulation of absorbed power, converted power and exported power using identical control methods. Power Matrix established based on power at grid connection point, using verified simulation to quantify the effect of using commercial control methods. Performance data to cover important points (e.g. at extremities) of the power matrix / operating envelope. Measured data using non-conservative operational control should be included. **Survivability (Operational):** Ability to maintain safe control of the device is demonstrated (end-stops, overspeeds, etc). **Survivability (Storm):** Structure certified as necessary to meet all relevant requirements of appointed classification society to deploy and operate at ocean test site. **Power Quality:** Grid Connected and control / power quality studies undertaken with a view to achieving grid code compliance. Power System simulation verified from measurements. Results demonstrating that farm grid code compliance is achievable. **Health Monitoring:** System in-place and any issues arising to be logged in a reporting system. Examples include: • Load Monitoring (moorings, PTO interfaces, etc) • Wear surfaces: bearings, seals, lubricant contaminants • Umbilical & Mooring cable rope inspections • Marine Growth , Corrosion **System Definition (commercial):** Detail design complete and ready for procurement exercise for a pre-commercial demonstration (TRL 8)	**Ocean Experience** **Health & Safety:** Risk Assessments (HAZOP / HAZID) complete for all phases of demonstration project. Design/Process changes implemented to eliminate identified risk. Event Log in place to record hazardous events. **Insurability / Marine Warranty:** Device certified by classification society to meet insurance conditions. Marine Warranties received for all marine operations associated with installation, deployment and scheduled maintenance. Plan to bring underwriting costs in-line with commercial requirements. **Environmental:** Environmental study complete and monitoring underway. Permitting process established for future projects. **Reliability:** Health monitoring / Failure / Issue reporting System updated with ocean project experience. FMEA updated as necessary and design/process change action taken to mitigate all issues highlighted for future projects. **Operability:** Commercial SCADA interface and operational procedures for the device in place. **Maintainability:** Marine operations required for scheduled maintenance and repair intervention are demonstrated. Improvements (cost-cutting, weather window restrictions, safety) defined to meet commercial operations requirements. **Deployability:** Installation operations and civil works at test site are demonstrated. The impacts on possible variations at future sites are studied in detail (scale, depth, geotechnics and environmental loads). **Manufacturability:** Supplier appraisal and contracting for pre-commercial demonstrator. **Economic Viability:** Update of costs and power production in economic model as appropriate.	**Consistent with ESBI Requirements:** ☐ Safe control of device demonstrated at extremeties of operating envelope. ☐ Power matrix based on measured electrical power in the operational environment at 1:2 scale or larger. ☐ Commercial Power matrix extrapolated through simulation (verified by 1:2 scale experiments) of converted power at grid connection. ☐ Appropriate level of certification achieved and insurance obtained. Mooring system and structure behave as expected in storm conditions. ☐ Measured power used as input to electrical power system model to demonstrate grid code compliance. ☐ Environmental scoping reports and monitoring data available. ☐ Commercial SCADA and remote supervisory control demonstrated. ☐ Health & Safety Risk Assessment and event logs received with appropriate mitigating action taken. ☐ Health monitoring / Failure reporting log available. FMEA updated and mitigating action taken on design / marine operations procedures. ☐ Supply chain report and plan for TRL8 hardware delivery in place. ☐ Detailed definition of TRL8 pre-commercial demonstrator available. ☐ Economic model updated with latest costs and performance indications.	**Spend:** €10-15m **Power Revenue:** €0-100k /an **Funding Mix:** Govt Grant Aid. Strategic investment (VC, utility, system integrator) **Duration:** 12-24 months **Team:** 20-40 staff covering marine operations, mechanical fitting, reliability, safety, etc.
ESBI Technology Partnership Readiness Level 3 Achieved			

ESBI TRL 8 – Pre-Commercial Project Readiness – 1:1 commercial scale single device hardware tested and demonstrated

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Actual Technology system completed and qualified through test and demonstration. **HMRC Development and Evaluation Protocol PHASE 5** Full scale end-to-end system (designed for the target market environmental conditions) deployed and operating at an ocean test site (Belmullet or similar). **Performance:** Operational experience sufficient to densely populate the Power Matrix table based on electrical power measured at grid point of connection, in accordance with IEC62600-100. Variations in power production for relevant environmental phenomena should be studied (wave direction, currents, etc.). Suitable assumptions to be used for pre-commercial power matrix should be defined and justified. **Power Quality:** Grid Code Compliance demonstrated through on-site testing (e.g. IEC 61000, IEC61400-21, etc) **Operability:** SCADA and operational procedures in place to permit 24 hour operation of device (preferably by utility partner). The operating envelope should be as commercial. **Survivability:** There should be no requirement to restrict on-site presence due to weather events. Mooring, foundation and anchoring system should be designed and operated as intended for commercial deployments. Geotechnical & depth differences between the deployment and commercial sites should not require further mooring development. **Health Monitoring:** System in-place and any issues arising to be logged in a reporting system. Examples include: • Load Monitoring (moorings, PTO interfaces, etc) • Wear surfaces: bearings, seals, lubricant contaminants • Umbilical & Mooring cable rope inspections • Marine Growth , Corrosion Parameters such as the above to be compared with expectations from simulation, etc. **System Definition:** Drawings and specifications sufficient to procure all subsystems. Requirements document for power export system for arrays. Installation and maintenance manual defining all marine operations.	**Actual Marine Operations completed and qualified through test and demonstration.** **Health & Safety:** Risk Assessments (HAZOP / HAZID) complete for all phases of demonstration project. Design/Process changes implemented to eliminate identified risk. Event Log in place to catch arising risks. **Maintainability:** All scheduled maintenance operations successfully completed, including electrical infrastructure where appropriate. **Reliability:** In-service data available for power station availability. Design / Process change action taken to mitigate all issues highlighted by the failure reporting system during deployment. FMEA database updated and data on subsystem failure rates gathered. **Environmental:** Results of Environmental monitoring report showing acceptable impact. **Supply Chain / Manufacturability:** Appraisal of supplier performance on project delivery and capacity to expand production towards commercial projects. **Insurability / Marine Warranty:** Device certified by classification society to meet insurance conditions. Marine Warranties received for all marine operations associated with installation, deployment and scheduled maintenance. Plan to bring underwriting costs in-line with commercial requirements. **Economics:** CAPEX and OPEX values updated in commercial economic model. Pre-commercial project (TRL9) financing: Hardware pricing and operations pricing agreed to support a >5MW pre-commercial array to achieve TRL 9. Pre-commercial project co-financing opportunities in place.	**Consistent with ESBI Requirements:** ☐ Measured power matrix results including variability. Report detailing environmental influences on performance and method for predicting energy production at a commercial site. ☐ Installation & scheduled maintenance operations completed and consistent ☐ Health & Safety Risk Assessment and event logs received with appropriate mitigating action taken. ☐ Health Monitoring System in place. Failure Reporting Log received. FMEA updated with appropriate mitigating action taken. ☐ 24-7 operability achieved ☐ Mooring system deployable at commercial site. ☐ Suitable Insurance cover received for assets and operations. ☐ Acceptable environmental impact demonstrated. ☐ Commercial economic model updated with latest cost & production estimates ☐ Supply chain for all subsystems and services is capable of expansion to deliver pre-commercial (TRL9) activity. ☐ Pre-commercial TRL9 project economic model formulated, opportunities highlighted and co-financing partners in place.	**Spend:** €10-15m **Power Revenue:** €100k–500k /an **Funding Mix:** Govt Grant Aid. Institutional and Strategic investment (VC, utility, system integrator). Possibly partially raised against owner operator power purchase agreement. **Duration:** 12-24 months **Team:** Up to 60 staff, expanded to cover marine operations, mechanical fitting, reliability, safety, commercial contracts, etc.
ESBI Pre-Commercial Project Readiness Level Achieved			

ESBI TRL 9 – Commercial Project Readiness – 1:1 commercial scale small farm (5MW or greater) operational experience.

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Operational performance and reliability of an array demonstrated **Operability:** Farm supervisory control handed over to a Utility / Owner-operator partner. **Performance (Measured):** Operational array of 5MW or larger wave farm. Farm power matrix at grid connection point confirmed and compared to individual device power matrix. Device interaction understood and accounted for. **Performance (Simulated):** Simulation capability used to extrapolate from measured performance to a larger farm production in a resource at a consented site. Energy production predicted with allowances made for sources of deviation from power matrix summary statistics as well as electrical topography. **Power Quality:** Grid Code Compliance demonstrated through on-site testing (e.g. IEC 61000, IEC61400-21, etc) **Health Monitoring:** System in-place and any issues arising to be reported in Issue reporting system. Examples include: • Load Monitoring (moorings, PTO interfaces, etc) • Wear surfaces: bearings, seals, lubricant contaminants • Umbilical & Mooring cable rope inspections • Marine Growth • Corrosion Parameters such as the above to be compared with expectations from simulation etc and deviations should be logged. **System Definition:** Product specification suitable for tender response. Design definitions, drawings etc for all subsytems and their integration for a wave farm.	**Fully de-risked business plan for utility scale deployment of arrays** **Health & Safety:** Risk Assessments for all phases of project lifecycle complete. Event logs up-to-date and design / process change action taken to mitigate all issues highlighted. **Maintainability:** All scheduled maintenance operations successfully completed and costs recorded, including electrical infrastructure where appropriate. Methods should represent commercial intent at this stage. **Reliability:** In-service data available for power station availability. Design / Process change action taken to mitigate all issues highlighted by the failure reporting system. Quantified FMECA database and repair intervention cost estimates. **Environmental:** Consenting and environmental monitoring activity complete. Benign impact on environment demonstrated sufficiently to show no obstacles to consenting and operations on commercial scale sites. **Insurability / Marine Warranty:** Underwriter's quotations for insuring assets and scheduled marine operations are available. **Economics:** Pricing of quayside hardware & installation operations given for a commercial project. Pricing of scheduled maintenance and intervention activity given for commercial operation. **Warranty:** Systems suppliers can stand over suitable commercial warranty based on power matrix guarantee and availability of hardware.	**Consistent with ESBI Requirements:** ☐ Health & Safety Risk Assessment and event logs received with appropriate mitigating action taken. ☐ Failure Reporting Log received with appropriate mitigating action taken. ☐ Wave farm energy production report received with measured power matrix. Based on a project proposal for a given site, with known resource: ☐ Wave farm energy production estimates based on measured farm power matrix. ☐ Quayside hardware specification and pricing. ☐ Installation & scheduled maintenance operations scope and pricing. ☐ Balance of plant (electrical, civil works etc) costs based on quotation. ☐ FMEA and reliability assessment undertaken giving repair cost liability. ☐ Insurance costs available ☐ Warranty available and liabilities backed up by provider's balance sheet. Considering all of the above and the available wave energy tariff: ☐ An acceptable project rate of return is achievable on project proposal.	**Spend:** €40-60m **Power Revenue:** €1m – 2m /an **Funding Mix:** Govt Grant Aid, particularly for generic electrical infrastructure. Owner-operator (utility) finance or finance raised against power purchase agreement. VC investments. **Duration:** 24 months – 20 yrs **Team:** Up to 100 staff depending on sub-contracting strategy. Mobilised supply chain at subsystem level. Strong support from a utility / owner-operator partner.
ESBI Commercial Project Readiness Level Achieved			