

# **Client: Sustainable Energy Authority of Ireland**

# Appendix 2 Technology Readiness Levels for Supply Chain Study for WestWave ESBloe-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 :
<ul> <li>Basic principles observed and reported</li> <li>System Definition: <ul> <li>Oscillator(s) with wave absorbing hydrodynamic interface identified</li> <li>Oscillator(s) with acceptable / controllable mechanical impedance identified</li> <li>Reacting bodies / PTO opportunity identified</li> <li>Relevant physical processes identified</li> <li>Station-keeping/foundation opportunity identified</li> </ul> </li> </ul>	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.	Market Identified	Consistent with ESBI Requirements:	<b>Spend:</b> €10-50k
System Definition: Principal dimensions and main components identified. Target	Site Identification: Suitable sites identified for large scale mobilisation of technology.	Concept configuration drawing	Power Revenue:
water depth and wave resource requirements identified. Basic geotechnical requirements identified. Scope of system and	Lifecycle considerations: The concept	Concept report defining system layout, function, site requirements and	None
external interfaces defined.	configuration should include consideration of manufacturability, deployability, access for	appreciation of lifecycle implications.	Funding: None
Performance/Costs: Simple calculations and read across	maintenance, operability and decommissioning.	Performance and cost calculations	
from existing data to estimate power production performance and size of major structural elements.	Health and safety hazards should be identified and designed out where possible.	/estimates indicating realistic targets.	Duration: 2-3 months
		Device configuration and sizing	
<b>Mechanical Integrity:</b> Configuration consistent with survivability for the target ocean environment.	<b>Customer Interface:</b> Point of sale of product and interface with customer is defined. (e.g. national grid connection point, etc)	consistent with offshore experience.	<b>Team:</b> Inventor

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
<ul> <li>Functional Readiness</li> <li>Analytical and experimental critical function and/or characteristic proof-of-concept.</li> <li>HMRC Development and Evaluation Protocol PHASE 1</li> <li>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&amp;E.P).</li> <li>Performance: Numerical simulation model in time domain – nviscid hydrodynamics, rigid body motions and idealised control forces to predict power absorbed by device.</li> <li>Survival: Moorings Analytical Simulation Model: Representative survival events to predict design wave response and define initial mooring sizing and induced loads.</li> <li>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.</li> <li>System Definition: Principal dimensions and inertial nformation, ensuring static stability, acceptable dynamic behaviour, etc. PTO degree of freedom defined (eg as linear PTO including stroke and peak force requirements, air turbine ncluding peak volume flows and damping coefficients)</li> </ul>	Lifecycle Readiness 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.	ESBI Verification Checklist         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.	Indicative : 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 Suppor

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

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

#### **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	Supply-chain Mobilisation	Consistent with ESBI Requirements:	Spend:
subsystem validation in a relevant environment.	Major Subsystem Integrators consulted and		€3-5m
	actively working on meeting subsystem	Simulation predictions of device	
HMRC Development and Evaluation PHASE 3	requirements	motion shown to match measured	<b>Power Revenue:</b>
(Lab Tests / fetch-limited site)		response of structure in basin / sea.	None
	Health & Safety: Risk Assessments (HAZOP /		
Absorber:	HAZID) complete for all phases of scaled sea /	PTO conversion simulation and large	Funding Mix:
Performance: Experimental verification of 1:4-1:15 scale (or	lake / basin trial activity. Design/Process changes	scale experimental testing indicating	Govt Research
arger) moored structure in large basin facility or benign site.	implemented to eliminate identified risks. Event	that the required conversion efficiency	Grants. Strategic
Measurement of dynamic response to operational sea-state	Log in place to catch arising risks and hazardous	can be achieved for power flows	investment (VC,
excitation. Conservative control methods may be employed	events. Impacts on commercial product	associated with irregular waves.	utility, system
at this stage. Measured response behaviour compared to expectations from numerical simulation for validation.	considered.	Updated power matrix based on	integrator)
Validated simulation used to extrapolate performance to full-	Health & Safety / Insurability: In respect of	validated simulation & PTO conversion	Duration:
scale with fully operational control.	sea / lake trials, inspections and reports by a	efficiencies.	12-18 months
Survivability: Experimental 1:4-1:15 scale (or larger)	marine surveyor / classification society should be	enciencies.	12-10 11011(13
moored structure exposed to scaled storm events in the sea.	used to obtain all insurance deemed necessary.	Scaled storm survival and acceptable	Team:
Mooring forces measured and compared to numerical model	used to obtain an insurance decined necessary.	mooring loads. Measurements	10-15 staff covering
predictions.	Interface Management: Supply chain feedback	consistent with simulation predictions.	simulation, control
	and interaction used to define important interfaces		structural, electric
PTO / End-stop control: Experimental verification of PTO	and to iterate the system level definition.	SCADA for remote control of an	design & definition
system at 1:4 (or larger) Froude scale power levels in	,	offshore system developed.	commercial &
aboratory environment (or within scaled sea-trial oscillator).	Maintainability / Deployability (commercial):		procurement. Plus
	Intervention and deployment operations	Health & Safety HAZID / HAZOP	subcontract suppo
Power Export: Experimental verification at 1:4 scale or	described. Warranty Surveyors assessment of	reports and effected design changes.	& steel fabrication.
arger of any unconventional components. (e.g. mechanical	planned marine operations is available.	Event log procedure in place.	
ntegrity of electrical risers in large waves/shallow water,			
marinised electrical substations, 11kV wet mate connectors)	Manufacturability (commercial): Consultation	Marine surveyors consulted for large	
	with potential suppliers on fabrication and	scale experimental work. Appropriate	
Naval Architecture: Static and Dynamic stability and other	assembly at commercial scale. Design update as	insurance obtained for activity.	
naval architecture concerns are addressed. Early structural ayouts for commercial scale complete. Detail designs for	required.	Warranty surveyor assessment of	
TRL 6 scale structure.	Manufacturability (next phase): Structural	proposed deployment and intervention	
	design, fabrication, assembly and fit-out of TRL 6	marine operations.	
Operability / SCADA: SCADA and telemetry developed to	structure at advanced stage of planning with	marme operations.	
support large scale experiments control and data acquisition.	suppliers consulted.	Commercial system definition	
support large scale experiments control and data dequisition		updated with supplier derived data.	
System Definition (commercial): System and interface	Deployability (next phase): TRL 6 Installation		
definition for commercial scale system is further detailed and	& Removal Operations of foundation, mooring	$\Box$ TRL 6 hardware system definition,	
updated with supplier feedback and test information.	systems and device from quayside to	experimental plan, fabricators and	
	experimental site are defined.	marine operations suppliers in place.	
System Definition (next phase): Full detail design			
definition for 1:4 (or larger) scale system and subsystems	Economic Viability: Updated business model	Commercial business model updated	
suitable for procurement exercise for TRL 6 testing.	using supplier derived cost estimates and where	with converted energy production and	
Experimental schedule for TRL 6 testing drafted.	possible, guotations.	supplier derived cost estimates.	1

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology <u>system</u> model or prototype demonstration in	Customer interaction	Consistent with ESBI Requirements:	Spend:
a relevant environment.	Discussions with potential owner-operators of	Power matrix based on measure of	€5m
	technology to establish project requirements.	absorbed power in the relevant	
HMRC Development and Evaluation PHASE 3		environment at 1:4 scale or larger.	Power Revenue:
(Sea Trials) Representative (1:4 scale or larger) full system	Health & Safety: Risk Assessments (HAZOP /		None
(excl power export) deployed and operating at a sea test site.	HAZID) complete for all phases of sea-trial	Commercial Power matrix	
DTO / Fad atom controls Franciscontal DTO system dealers d	activity. Design/Process changes implemented	extrapolated through simulation of	Funding Mix:
PTO / End-stop control: Experimental PTO system deployed	to eliminate identified risk. Event Log in place to	converted power at grid connection point.	Govt Research
should be as required to test aspects of control and absorbed	catch arising risks and hazardous events.	(verified by 1:4 scale experiments)	Grants. Strategic investment (VC,
power. Heavily instrumented 1:4 Froude scale power output (or larger) operating within the system at sea to produce	Impacts on commercial product considered.	Electrical system simulation	utility, system
electricity. Electricity need not be exported.	Health & Safety / Insurability: In respect of	demonstrates grid compliant power using	integrator)
electricity. Electricity need not be exported.	sea trials, inspections and reports by a marine	measured electrical power as an input.	integrator)
Performance: Experimental Sea Trials of technology	surveyor / classification society should be used	measured electrical power as an input.	Duration:
configuration in scaled wave resources (1:4 scale or larger –	to obtain all insurance deemed necessary.	Health & Safety HAZID / HAZOP	12-18 months
e.g. Galway Bay). Based upon electrical power at the device	to obtain an insurance decined necessary.	reports and effected design changes.	12 10 11011113
terminals (pre-export), verification of a range of operating	Reliability: Detailed FMEA to sub-system levels	Event log procedure, acceptable	Team:
conditions in the power matrix should be carried out. The	including supplier input on major subsystems.	insurance and certification in place.	15-20 staff
deviation from idealised simulation predictions due to relevant		······································	covering simulation
environmental phenomena should be established.	Failure / Issue reporting System: Failure &	Mooring and structural integrity	& control,
•	Issue reporting system in place for duration of	demonstrated in maximum operating	structural,
<b>Power Quality:</b> Simulations of generator and power export	the deployment to record all operational faults	conditions and storm survival conditions.	electrical design &
system, supported by experimental mechanical (e.g. shaft)	and issues that arise. FMEA, design/process		definition,
and electrical power measurements in the relevant	change enacted to reflect arising issues.	Detailed FMEA and failure reporting	commercial &
environment. Results showing that grid code compliance (e.g.		system in place. Marine environment	procurement. Plus
IEC 61000, IEC61400-21, etc) is achievable.	<b>Operations &amp; Maintenance:</b> Supervisory	effects logged and appropriate design /	subcontract
	control of the device from shore should be	process change action taken.	support & steel
<b>Survivability:</b> Site should be selected so that the 1:1 year	demonstrated. Operations plan and lifecycle		fabrication.
return period storm is similar to or more severe than a scaled	maintenance and intervention schedule for	Updated commercial system	
1:100 year return period storm at commercial scale. The test	typical commercial project is supported by	definition. O&M plan formulated in detail	
mooring subsystem should be representative of commercial	potential O&M suppliers. Customer buy-in that O&M plan meets their requirements.	by suppliers. Customer vetting of O&M.	
intent and certifiable. Survival mode features (e.g. detuning) should be tested. Measurements taken for model validation.	Oam plan meets their requirements.	□ TRL 7 detailed system definition	
	Manufacturability: Advanced plans for supply	complete. Hardware suppliers identified.	
Marine Environment: The effect of marine environment on	of TRL7 subsystems, fabrication and assembly.	complete. Hardware suppliers identified.	
the device growth and corrosion protection systems to be	Supplier quotations / cost estimates available.	□ TRL 7 installation operations detailed	
considered. Learning applied to commercial definition.		with a view to validating commercial	
	Deployability: Advanced plans for one-off	intentions.	
System Definition (commercial): System and interface	deployments with a view to validating		
definition for commercial scale system is further detailed and	commercial intentions. (geotechnics, vessel,etc)	Customer agreed commercial project	
updated with customer/supplier feedback and test information.	(3,,,	economic model. CAPEX/OPEX costs	
	Economic Viability: Updated economic model	consistent with supply chain indications.	
System Definition (next phase TRL7): Low level	based upon customer requirements for early	Energy production consistent.	
requirements definition of commercial scale system and all	projects. Use of supplier derived costs and		
subsystems, sufficient to enable detail design exercise to	where possible, quotations. OPEX cost including		
commence. Marine Operations storyboard and requirements	supplier derived information for marine		
	operations & vessel hire should be included.		
document. Experimental schedule for TRL 7 testing drafted.	nology Partnership Readiness Level 2		

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

echnology <u>system</u> prototype demonstration in an	Ocean Experience	Consistent with ESBI Requirements:	Spend:
perational environment.			€10-15m
	Health & Safety: Risk Assessments (HAZOP /	Safe control of device demonstrated	
MRC Development and Evaluation Protocol PHASE 4	HAZID) complete for all phases of demonstration	at extremeties of operating envelope.	Power Revenue:
epresentative (1:2 scale or larger) end-to-end system	project. Design/Process changes implemented		€0-100k /an
eployed and operating grid-connected at an ocean test site	to eliminate identified risk. Event Log in place to	Power matrix based on measured	Funding Miss
MEC or similar).	record hazardous events.	electrical power in the operational environment at 1:2 scale or larger.	Funding Mix: Govt Grant Aid.
perability: Initial conservative operational restrictions in	Insurability / Marine Warranty: Device	environment at 1:2 scale of larger.	Strategic
ace as necessary. Conservative control methods slowly	certified by classification society to meet	Commercial Power matrix	investment (VC,
elaxed with operational experience. Validation of some power		extrapolated through simulation	utility, system
atrix points based on commercial control methods.	received for all marine operations associated	(verified by 1:2 scale experiments) of	integrator)
	with installation, deployment and scheduled	converted power at grid connection.	integrator)
erformance: Comparisons of measured power with	maintenance. Plan to bring underwriting costs	converted power de grid connection.	Duration:
redictions from simulation of absorbed power, converted	in-line with commercial requirements.	Appropriate level of certification	12-24 months
ower and exported power using identical control methods.		achieved and insurance obtained.	
ower Matrix established based on power at grid connection	Environmental: Environmental study complete	Mooring system and structure behave as	Team:
pint, using verified simulation to quantify the effect of using	and monitoring underway. Permitting process	expected in storm conditions.	20-40 staff covering
ommercial control methods. Performance data to cover	established for future projects.		marine operations,
nportant points (e.g. at extremities) of the power matrix /		Measured power used as input to	mechanical fitting,
perating envelope. Measured data using non-conservative	Reliability: Health monitoring / Failure / Issue	electrical power system model to	reliability, safety,
perational control should be included.	reporting System updated with ocean project	demonstrate grid code compliance.	etc.
	experience. FMEA updated as necessary and		
urvivability (Operational): Ability to maintain safe contro	design/process change action taken to mitigate	Environmental scoping reports and	
the device is demonstrated (end-stops, overspeeds, etc).	all issues highlighted for future projects.	monitoring data available.	
urvivability (Storm): Structure certified as necessary to	<b>Operability:</b> Commercial SCADA interface and	Commercial SCADA and remote	
eet all relevant requirements of appointed classification	operational procedures for the device in place.	supervisory control demonstrated.	
ociety to deploy and operate at ocean test site.	- Friend		
	Maintainability: Marine operations required for	Health & Safety Risk Assessment and	
ower Quality: Grid Connected and control / power quality	scheduled maintenance and repair intervention	event logs received with appropriate	
udies undertaken with a view to achieving grid code	are demonstrated. Improvements (cost-cutting,	mitigating action taken.	
ompliance. Power System simulation verified from	weather window restrictions, safety) defined to		
easurements. Results demonstrating that farm grid code	meet commercial operations requirements.	Health monitoring / Failure reporting	
ompliance is achievable.		log available. FMEA updated and	
	Deployability: Installation operations and civil	mitigating action taken on design /	
ealth Monitoring: System in-place and any issues arising t		marine operations procedures.	
e logged in a reporting system. Examples include:	impacts on possible variations at future sites are		
Load Monitoring (moorings, PTO interfaces, etc)	studied in detail (scale, depth, geotechnics and	Supply chain report and plan for	
Wear surfaces: bearings, seals, lubricant contaminants	environmental loads).	TRL8 hardware delivery in place.	
Umbilical & Mooring cable rope inspections	Manufacture hillton Constitution annual data		
Marine Growth , Corrosion	Manufacturability: Supplier appraisal and	Detailed definition of TRL8 pre-	
ustom Definition (commercial). Detail design security	contracting for pre-commercial demonstrator.	commercial demonstrator available.	
ystem Definition (commercial): Detail design complete nd ready for procurement exercise for a pre-commercial	Economic Viability: Update of costs and power	Economic model updated with latest	
emonstration (TRL 8)	production in economic model as appropriate.	costs and performance indications.	
	production in economic model as appropriate.		
FCRI Te	chnology Partnership Readiness Level	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 :	
Actual Technology system completed and qualified	Actual Marine Operations completed and	<b>Consistent with ESBI Requirements:</b>	Spend:	
through test and demonstration.	qualified through test and demonstration.		€10-15m	
		Measured power matrix results		
HMRC Development and Evaluation Protocol PHASE 5	Health & Safety: Risk Assessments (HAZOP /	including variability. Report detailing	Power Revenue:	
Full scale end-to-end system (designed for the target market	HAZID) complete for all phases of demonstration	environmental influences on	€100k-500k /an	
environmental conditions) deployed and operating at an ocean	project. Design/Process changes implemented	performance and method for predicting		
test site (Belmullet or similar).	to eliminate identified risk. Event Log in place to catch arising risks.	energy production at a commercial site.	Funding Mix: Govt Grant Aid.	
Performance: Operational experience sufficient to densely	·····	□ Installation & scheduled maintenance	Institutional and	
populate the Power Matrix table based on electrical power	Maintainability: All scheduled maintenance	operations completed and consistent	Strategic	
neasured at grid point of connection, in accordance with	operations successfully completed, including		investment (VC,	
EC62600-100. Variations in power production for relevant	electrical infrastructure where appropriate.	Health & Safety Risk Assessment and	utility, system	
environmental phenomena should be studied (wave direction,	<b>Deliability</b> . In convice data available for newer	event logs received with appropriate	integrator).	
currents, etc.). Suitable assumptions to be used for pre- commercial power matrix should be defined and justified.	<b>Reliability:</b> In-service data available for power station availability. Design / Process change	mitigating action taken.	Possibly partially raised against	
commercial power matrix should be defined and justified.	action taken to mitigate all issues highlighted by	Health Monitoring System in place.	owner operator	
<b>Power Quality:</b> Grid Code Compliance demonstrated through	the failure reporting system during deployment.	Failure Reporting Log received. FMEA	power purchase	
on-site testing (e.g. IEC 61000, IEC61400-21, etc)	FMEA database updated and data on subsystem	updated with appropriate mitigating	agreement.	
	failure rates gathered.	action taken.	agreement	
<b>Operability:</b> SCADA and operational procedures in place to			Duration:	
permit 24 hour operation of device (preferably by utility	Environmental: Results of Environmental	□ 24-7 operability achieved	12-24 months	
partner). The operating envelope should be as commercial.	monitoring report showing acceptable impact.			
		Mooring system deployable at	Team:	
Survivability: There should be no requirement to restrict on-	Supply Chain / Manufacturability: Appraisal	commercial site.	Up to 60 staff,	
site presence due to weather events. Mooring, foundation and	of supplier performance on project delivery and		expanded to cover	
anchoring system should be designed and operated as	capacity to expand production towards	Suitable Insurance cover received for	marine operations,	
ntended for commercial deployments. Geotechnical & depth	commercial projects.	assets and operations.	mechanical fitting,	
differences between the deployment and commercial sites	Theurshilling ( Marine Warnantus, Device		reliability, safety,	
should not require further mooring development.	Insurability / Marine Warranty: Device certified by classification society to meet	Acceptable environmental impact demonstrated.	commercial contracts, etc.	
Health Monitoring: System in-place and any issues arising to	insurance conditions. Marine Warranties	demonstrated.	contracts, etc.	
be logged in a reporting system. Examples include:	received for all marine operations associated	Commercial economic model updated		
<ul> <li>Load Monitoring (moorings, PTO interfaces, etc)</li> </ul>	with installation, deployment and scheduled	with latest cost & production estimates		
• Wear surfaces: bearings, seals, lubricant contaminants	maintenance. Plan to bring underwriting costs			
Umbilical & Mooring cable rope inspections	in-line with commercial requirements.	Supply chain for all subsystems and		
<ul> <li>Marine Growth , Corrosion</li> </ul>		services is capable of expansion to		
Parameters such as the above to be compared with	<b>Economics:</b> CAPEX and OPEX values updated in	deliver pre-commercial (TRL9) activity.		
expectations from simulation, etc.	commercial economic model. Pre-commercial			
	project (TRL9) financing: Hardware pricing and	Pre-commercial TRL9 project		
System Definition: Drawings and specifications sufficient to	operations pricing agreed to support a >5MW	economic model formulated,		
procure all subsystems. Requirements document for power	pre-commercial array to achieve TRL 9. Pre-	opportunities highlighted and co-		
export system for arrays. Installation and maintenance	commercial project co-financing opportunities in	financing partners in place.		
manual defining all marine operations.	place.			
ESBI Pre-Commercial Project Readiness Level Achieved				

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

lemonstrated       scale deployment of arrays	Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
<ul> <li>Health &amp; Safety: Risk Assessments for all tilty / Owner-operator partner.</li> <li>Health &amp; Safety: Risk Assessments for all phases of project lifecycle complete. Event logs received with appropriate mitigating action taken.</li> <li>Health &amp; Safety: Risk Assessments for all phases of project lifecycle complete. Event logs received with appropriate mitigating action taken.</li> <li>Health &amp; Safety: Risk Assessments for all phases of project lifecycle complete. Event logs received with appropriate mitigating action taken.</li> <li>Health &amp; Safety: Risk Assessments for all phases of project lifecycle complete. The process change action taken to mitigate all issues highlighted.</li> <li>Health &amp; Safety: Risk Assessments for all phases of project lifecycle complete. The province is a consent of site. Energy roduction report received with measured power matrix.</li> <li>Health &amp; Safety: Risk Assessments for all wave farm energy production report received with measured power matrix.</li> <li>Health &amp; Safety: Risk Assessments for all wave farm energy production report received with measured power matrix.</li> <li>Health &amp; Safety: Risk Assessment and the phases of project lifecycle complete. Health &amp; Safety: Risk Assessment and phases of project lifecycle complete. The proving system in-place and any issues arising and environmental monitoring gativity complete. Being impact on environment demonstrates sufficiently to show no obtacles to consenting and operations scenestify and operations con commercial scale sites.</li> <li>Health &amp; Safety: Risk Assessment and the analysis arising and operations for insuring assets and scheduled maintenance operations are available.</li> <li>Health &amp; Safety: Risk Assessment and the analysis phase of power appropriate. Methods should be project scale should and could and could be and inspirit.</li> <li>Health &amp; Safety: Risk Assessment and the propriate mitigating actin taken.</li> <li>Health &amp; Safety: Risk Assessment and the</li></ul>	Operational performance and reliability of an array	Fully de-risked business plan for utility	Consistent with ESBI Requirements:	
pperability: Farm supervisory control handed over to a litility / Owner-operator partner.       Health & Safety: Risk Assessments for all phases of project lifecy decomplete. Event logs received with appropriate mitigating action taken.       Power Revenue: Clim - Zm /an         phases of project lifecy decomplete.       Feature Assessment is project lifecy decomplete.       event logs received with appropriate mitigating action taken.       Power Revenue: Clim - Zm /an         phases of project lifecy decomplete.       feature Assessment is project lifecy decomplete.       event logs received with appropriate mitigating action taken.       Power Revenue: Clim - Zm /an         phases of project lifecy decomplete.       feature Assessment is project lifecy decomplete.       event logs received with appropriate mitigating action taken.       Power Revenue: Clim - Zm /an         phases of project lifecy decomplete.       feature Assessment is project lifecy decomplete.       event logs received with appropriate mitigating action taken.       Power Revenue: Clim - Zm /an         phases of project lifecy decomplete.       feature Assessment is project lifecy decomplete.       event logs received with appropriate mitigating action taken.       Power Assessment is project lifecy decomplete.       feature Assessment is projec	demonstrated	scale deployment of arrays		€40-60m
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<ul> <li>design / process change action taken to mitigate all issues highlighted.</li> <li>Hailure Reporting Log received with appropriate mitigating action taken.</li> <li>Failure Reporting Log received with appropriate mitigating action taken.</li> <li>Failure Reporting Log received with appropriate mitigating action taken.</li> <li>Hailure Reporting Log received with appropriate mitigating action taken.</li> <li>Hailure Reporting Log received with appropriate mitigating action taken.</li> <li>Wave farm energy production report received with measured power matrix.</li> <li>Bailure Reporting Log received with appropriate mitigating action taken.</li> <li>Wave farm energy production report received with measured power matrix.</li> <li>Wave farm energy production estimates taken to mitigate all issues highlighted by the failure reporting system. Canonical intent at this stage.</li> <li>Reliability: In-service data available for power attin. Summary statistics as well as learning from investing experiments in consenting and the failure reporting system. Examples include:</li> <li>Benjon impact and evaluations shoulde be reporting system. Examples include:</li> <li>Benjon impact and evaluations shoulde be reporting system. Examples include:</li> <li>Benjon impact and evaluation shoulde be reporting system. Examples include:</li> <li>Benjon impact and evaluation shoulde be reporting system. Examples include:</li> <li>Benjon impact and evaluation shoulde be reporting system. Examples include:</li> <li>Benjon impact and evaluation shoulde be reporting system. Support for a given or environment demonstrated sufficiency to show no obstacles to consenting and environmental monitoring downing, proving transpections for a given or a consenting and intervention activity to show no obstacles to consenting and environmental monitoring on coming, proving transpections shoulde be reporting system. Examples include:</li> <li>Benjon impact and evaluations fo</li></ul>				
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arger wave farm. Farm power matrix at grid connection onit confirmed and compared to individual device power natrix. Device interaction understood and accounted for.       Maintainability: All scheduled maintenance operations successfully completed and costs recorded, including electrical infrastructure where appropriate. Methods should represent comduction in a resource at a consented site. Energy roduction predicted with allowances made for sources of eviation from gower matrix.       Govt Grain Aid, particularly for generic electrical infrastructure.         Wave farm energy production report valtation from power matrix summary statistics as well as lectrical topography.       Maintainability: All scheduled maintenance operations successfully completed and onsavaliability. Design / Process change action taken to mitigate all issues highlighted by the failure reporting system. Quantified MECA database and repair intervention cost estimates. Lead Monitoring (e.g. IEC 61000.1 IEC61400-21, etc)       Wave farm energy production restimets.       Govt Grain Aid, particularly for generic electrical infrastructure.         Wave farm energy production sutters be reported in Issue reporting system. Examples include: Load Monitoring system. Examples include: Load Monitoring cable rope inspections Marine Growth Corrosion arameters such as the above to be compared with xpectations from simulation etc and deviations should be goged.       Insurability / Marine Warranty: Underwiter's quotations given for a commercial and operations given for a commercial aperation.       Insurance costs available intervention activity given for commercial operation.       Insurance costs available intervention activity given for commercial operation.       Insurance costs available subsystem level.       Strong support aparinte mitigating action taken. Insurance costs a	Performance (Measured): Operational array of 5MW or		Failure Reporting Log received with	Funding Mix:
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Performance (Simulated): Simulation capability used to       where appropriate. Methods should represent       Based on a project proposal or a given site, with known resource:       Owner-operator         vitation are source at a consented site. Energy roduction prover matrix summary statistics as well as learnical topography.       Methods should represent all issues highlighted by the failure reporting system. Quantified FME       Based on a project proposal or a given site, with known resource:       Owner-operator         vewer Quality: Grid Code Compliance demonstrated hrough on-site testing (e.g. IEC 61000, IEC61400-21, etc).       Design impact on environment all issues signification availability of and ware sections from simulation etc and deviations should be project and environment al monitoring activity complete. Benign impact on environment all monitoring activity consenting and operations consenting and operations consenting and operations consenting and operations socies as allable.       Duration:       24 months - 20 yrs         Wear surfaces: bearings, seals, lubricant contaminants Umblicial & Mooring cable rope inspections from simulation etc and deviations should be agged.       Insurability / Marine Warranty:       Insurability / Marine Warranty:       Insurability assessment undertaken giving repair cost liability.       Performance (or proposal or environment all isous report proposal or environment allow provider's balance sheet.       Duration:       24 months - 20 yrs         Environmental: Consenting and operations give for a commercial project. Pricing of scheduled maintenance and intervention sativity given for commercial project. Pricing of scheduled maintenance and intervention activity given for commercial project.	matrix. Device interaction understood and accounted for.	operations successfully completed and costs	Wave farm energy production report	
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	ECDT	Commercial Project Peadiness Level		<u> </u>

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