CúNaMara Floating Multiple-use Energy Harvesting Platform

JJ Campbells

1 Contents

1.1 Introduction

1.1.1 Combination type

Combines: Floating wind and wave technologySpace share type: Multi-use platform (MUP)

1.1.2 Company description

J.J. Campbell & Associates is a structural and civil engineering company with a variety of design projects including multi storey buildings, shopping centres, industrial and residential projects with public and private sector clients established in 1996 and having a reputation for delivering design and detail within budget and on time.

1.1.3 Combination project description

1.1.3.1 Current status

The technology is currently at TRL3. Proof of concept has been demonstrated at 1:50 scale through three phases of public/private funding leading to two rounds of tank testing and validated by Black and Veatch. A third tank testing campaign is currently underway.

1.1.3.2 Strategic Roadmap to commercialisation

The commercial development plan for the technology includes completion of 1:10 scale tank testing and then to design and build a 1:4 scale prototype for sea trials. Demonstrating the platform performance, power take-off and performing structural load tests to confirm key load calculations for a turbine to be installed will allow the technology to reach TRL6. Overall system stability and survivability will also be demonstrated. The next stage will be a pilot MUP floating wind/wave unit with platform nameplate rating of 24MW to achieve TRL7. A pre-commercial MUP farm consisting of 5 MUPs (TRL8) to operate over 20 years at a new site (location to be determined) will allow for expansion into a larger commercial project with total capacity of 480 MW (TRL9).

Figure 1.1: Location of pilot location (AMETS) and fabrication site (Foynes)

1.2 Technical Brief with Planned Phases of Development

1.1.1 Overview

The project aims to develop a MUP Pilot wind/wave energy harvesting platform (CúNaMara) designed to be deployed in wind and wave energy rich locations at water depths of between 80 metres and 100 metres. At a typical location, a single platform will produce approximately 77 GWhr of electricity per annum, equivalent to the electrical consumption of 21,000 homes. This is achieved through the combination of 8 MW installed wind and 16 MW installed wave capacity. Wave energy is captured using oscillating water columns (OWCs) and pneumatic turbines. At fully commercial level, it is envisaged that an energy farm will comprise of 20 such platforms.

1.1.3.1 TRL 4-5 Development phase

- Aim: Includes further 1:50 scale and 1:10 scale tank testing. Platform stability and power take-off will be studied.

- The description of this interim development phase was beyond the scope of MARIBE and not elaborated

1.1.3.2 EU proposed pilot: TRL6

- *Aim: Includes 1:4 scale sea trials. Platform performance, power take-off. Key load parameters for the platform and wind turbine to be confirmed. Overall system stability and survivability will be demonstrated.*

- *Comprises 1 MUP*
    - *Wind: A representative system to simulate key features of a wind turbine*
    - *WECs: Nose-piece platform footprint of approx. 26m X 13m with eight 31.25kW OWCs chambers at 1:4 scale*
- *Footprint combined approx. 26m X 13m*
- *Located: Galway Bay Ireland test site*
- *Water depth: 20m – 40m*
- *Fabricated at:*
    - *Wind turbine analogue: Galway*
    - *WECs and platform: Galway*
- *Brought to location by: towing vessel*
- *Installed using: towing vessel*
- *Cable to shore or power source: Grid connection available at Galway Bay test site*
- *Moorings: Standard off the shelf mooring technology used*
- *O/M and access: Galway Bay test site*
- *Platform to be removed from test site after 18 months with potential for redeployment as a niche product with potential for suitable wind turbine*
- ***Target deployment in: Target commencement date for sea trials in 2020***

1.1.3.3 TRL 7

- *Aim: Delivers a Pilot MUP floating wind/wave unit with platform nameplate rating of 24MW*

- *Comprises 1 MUP*
    - *Wind: one 8MW Vestas V164-8 wind turbine*
    - *WECs: thirty-two 500kW OWC chambers*
- *Footprint combined approx. 250 m X 450 m*
- *Located: WestWave or AMETS*
- *Water depth: 50m- 80m*

- *Fabricated at:*
    - *Wind turbine: towers, blades/turbine shipped to Foynes Port/ Shannon Estuary facilities*
    - *WECs, platform and tower fixings: Foynes Port/ Shannon Estuary facilities*
- *Brought to location by: towing vessel*
- *Installed using: towing/specialist vessel*
- *Cable to shore or power source: Grid connection available at proposed pilot sites*
- *Moorings: gravity based type constructed from reinforced concrete, using a dashpot type connection between the platform and the mooring*
- *O/M and access: Access is by work boats and mother ships or accommodation platforms. Provision for helicopter is included*
- ***Target deployment in: 2025***

1.1.3.4 TRL8 Pre-Commercial Farm – Location TBD

- Aim: Deliver a pre-commercial MUP farm consisting of 5 MUPs to operate over 20 years at a new site (location to be determined) allowing for expansion into a larger commercial project

- The description of this interim commercial phase was beyond the scope of MARIBE and not elaborated

1.1.3.5 TRL9 1st Commercial

- Aim: Deliver a commercial farm with total capacity of 480 MW, same location as TRL8

- The description of this interim commercial phase was beyond the scope of MARIBE and not elaborated

1.1.3.6 TRL9 2nd Commercial farm - Location TBD

- Aim: Deliver an MUP commercial floating wind and wave farm at a new site or similar MW size (location to be determined)

- The description of this interim commercial phase was beyond the scope of MARIBE and not elaborated

1.1.3.7 Commercial scale after 2 commercial scale projects - Location TBD

- Aim: Deliver a 3rd commercial farm, adopting full learning and cost reductions. Total capacity remaining the same at 480 MW.
- Comprises 20 MUPs
    - Wind: one 8MW Vestas V164-8 wind turbine/platform
    - WECs: thirty-two 500kW OWC chambers/platform
- Footprint combined approx. 7.5 km^2
- Located: off west coast of Europe e.g. Ireland’s Porcupine Bank or west of Scotland

- Water depth: 80 - 100 m
- Fabricated: Concrete hull to be fabricated at dedicated facility close to deployment site
- Brought to location/Installed: towing/specialist vessel
- Cable to shore or power source: Grid connection to shore at own cost
- Array connection or autonomous power: The array cable three core 33kV AC on fully flexible strings with provision to isolate an individual turbine, via J-tubes
- Moorings: gravity based/reinforced concrete
- O/M and access: Access is by work boats and mother ships or accommodation platforms. Provision for helicopter is included
- **Target deployment in: 2035**

Gantt

		2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
TRL5	**Tank Test**												
TRL6	**Galway Bay**												
TRL7	**1 unit**												
TRL8	**5 units**												
TRL9	**First commercial**												
TRL9	**Full commercial**												

Table 1: Roadmap to commercialisation

1.1.2 Advantage of combination

1. Two non-correlated out-of-phase power sources on one platform resulting in smoother power delivery and obviating the need for storage
2. Cost savings on materials by combining on one floating platform
3. Cost savings on O & M due to 'harbour' effect
4. Cost savings arising from shared wind & wave electrical infrastructure
5. Conforms to EU directives on multi-use of space and MSP directives
6. High local content for deployment areas on the periphery of Europe

1.3 Business section

1.1.1 Competition

Table 2: Key Competitors

Competitor	**Key Differentiators**	**Competitive Threat Rating (1-5)***
Floating Power Plant (Poseidon Device)	Following pilot testing, Poseidon 80 model is being developed. The model is intended to have up to 5MW wind and up to 2.6MW wave power. The main energy source being harnessed is wind energy.	**3**
KNSwing Device	The ship-like device incorporates 20 Oscillating Water Columns on each side. Full scale device is approximately 150 metres long and estimated to absorb 2.9MW.	**3.5**
Pelagic Power (W2Power Device)	W2Power is a lightweight semi-submersible floating platform for a combination of both wind and wave energy converters. Although the device is similar, the primary energy source the W2Power device is wind energy. W2Power does not have the scalability of the Cúnamara device due to its lack of modular construction.	**2.5**
Renewable Energy Sources	In terms of the Irish and UK market, the largest renewable energy source is the fixed onshore wind industry. This industry has a well-established supply chain and portfolio of existing sites.	**4**
Fossil Fuel Sources	The global energy market has continued to be dominated by oil based sources. Natural gas has been considered the main fuel of choice when substituting for oil sources and has been branded as a low-carbon alternative.	**1.5**

***Competitive threat based on companies' appraisal of perceived threat with 5 being severe competitive threat.**

1.1.2 Business Model

This business model is of the category type (defined in the Introduction) as ***'technology device developer and seller'*** where the main revenue is from the sale of devices to project developers. The following business model canvas for commercial phase of development is presented:

Table 3: Business Model Canvas Building Blocks

1. **Customer Segments**

- Potential customers include Vattenfall, E.ON, DONG Energy, ESB International and Statoil.

2. **Value Proposition**

- Oscillating Water Column (OWC) technology is one of the most proven methods of converting wave energy.
- Floating platform allows the device to generate electricity in greater water depths.
- The modular nature of the platform allows for additional hull units to be installed.
- Low cost – the concrete construction is more cost effective.
- Having two renewable energy technologies on one platform improves brand image.
- JJ Campbell's excellent track record will be encouraging for project developers.

3. **Channels**

- *Sales*: Direct selling will be JJ Campbell's best method to reach customers.
- *Marketing*: channels include content marketing, event marketing and online marketing.
- *Physical distribution*: the finished devices can be towed to the customer's final location with the use of conventional towboats eliminating the need for specialist vessels.

4. **Customer Relationships**

- A close partnership with customers will enhance relationships and give JJ Campbell a competitive advantage over competitors.

5. **Revenue Streams**

- Revenue streams includes sale of devices, operation and maintenance, licensing of technology and consultancy.

6. **Key Resources**

- Proven technology (TRL9), specialised workforce and expertise, specialised services (external), Intellectual Property (technology protection).

7. **Key Activities**

- R&D, customer development, managing manufacturing process (coordinating contractors), operations and maintenance (required on most contracts sales lately), Intellectual Property management.

8. **Key Partners**

- Government Investment Agencies such as the National Treasury Management Agency.
- Investment funds such as the US-based Carlyle Fund for Ireland.
- Research centres and academic partners such as the centre for Marine and Renewable Energy Ireland in University College Cork.
- Customers, suppliers.

9. **Cost Structure**

- The costs that JJ Campbell will incur during commercial operation include continued R&D, device construction, operations and maintenance (required on most contract sales), overheads and IP management.

1.4 Management Section

1.1.1 Existing management team and company organisational structure

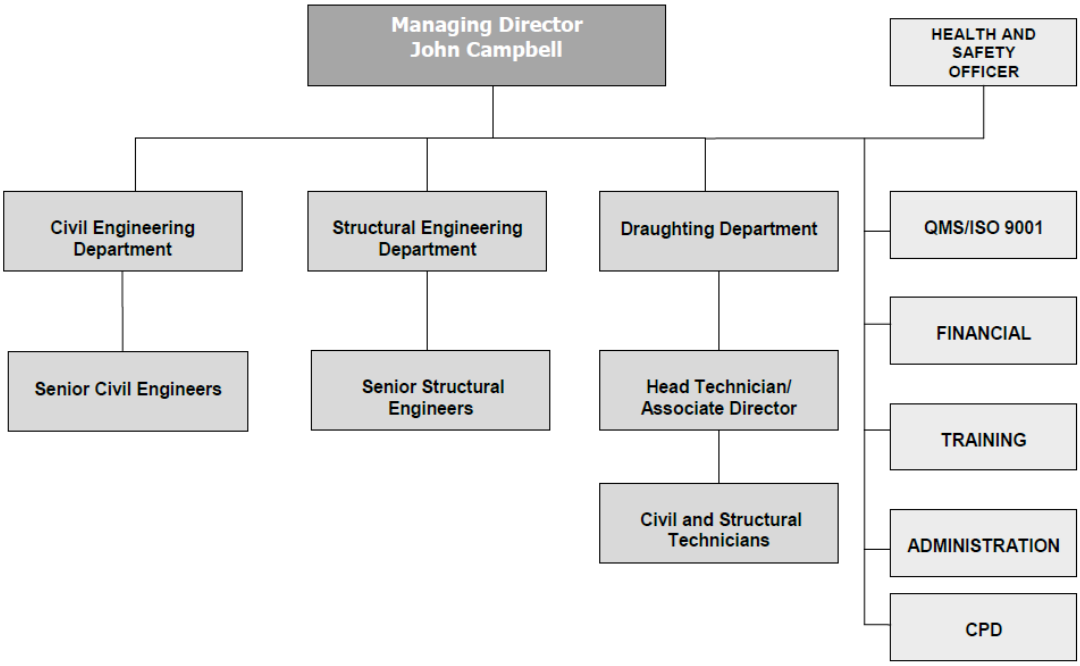

Figure 2: Management structure

The key activities off J.J. Campbell & Associates as a company consist of consulting engineering services, structural & civil. architectural services, project management and risk management, environmental engineering services, quantity surveying services, marine research & development.

The organisational structure of J.J. Campbell & Associates is illustrated in Figure 2. The decision-making process is based on decades of experience combined with the analysis of reliable and accurate data and information.

For this combination, it is anticipated that the management team contains all the requisite skills and expertise necessary in order to accomplish the project goals under the business model of “technology provider” and outsourcing to external service providers. The preferred option following completion of design to best exploit the product under the proposed business model is to manage the project from FID (Financial Investment Decision) to WCD (Work Completion Date) through an Special Purpose Vehicle (SPV).

1.5 Market Section: Market Share from 2020 until 2040

1.1.1 Market Analysis

The market analysis indicates that there is a large market available worldwide for a combination technology of wave and floating wind. This includes Ireland, UK, mainland Europe, USA and Australia, South Africa and Asia. In Ireland and UK the overall potential market size for CúNaMara devices is 2750 by 2050 for wind/wave.

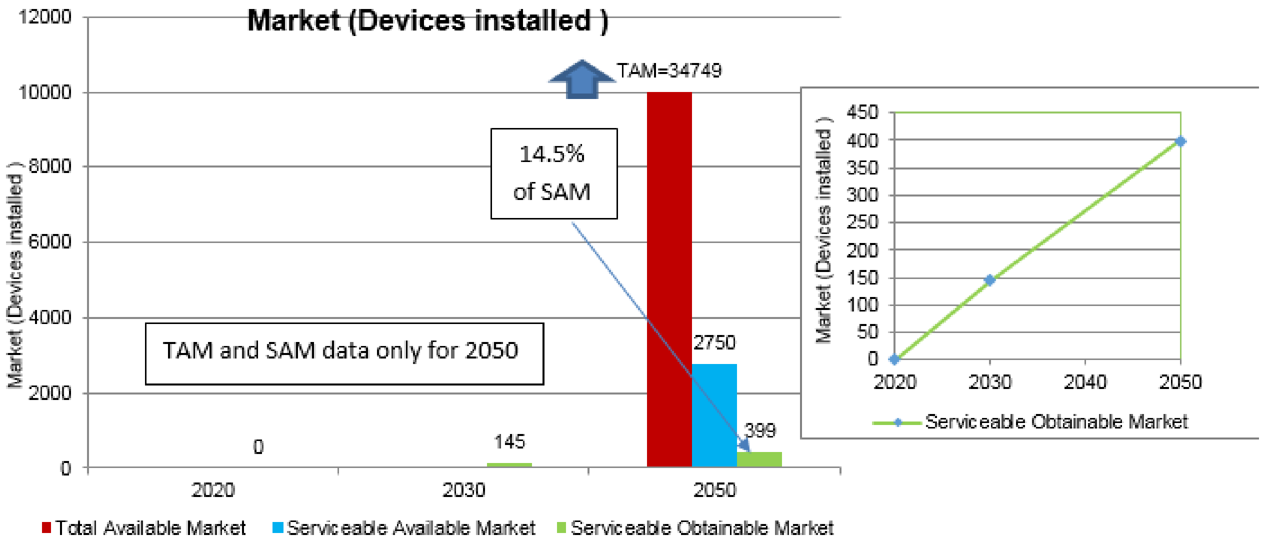

Figure 3: Market Analysis: Devices

Figure 3 illustrates the potential total market and potential serviceable obtainable market. This is an ambitious target and would require a wholesale change in energy policy towards green energy on a national and international level.

1.1.2 List of investors and sources of funding

1.1.3.1 Investors and funding to date

- TRL 1-3: € 750,000. This funding has been used to complete the TRL 1-3 process and includes SEAI grants.
- In-kind contributions
    - Dedicated engineering expertise over the course of the project to TRL level achieved to date time
    - Participation in other projects (e.g. MARINA)

1.1.3.2 Grants funds required and potential sources

- TRL 4-5: € 2 million plus - Estimate agreed with SEAI following engagement with Black & Veatch to be funded 80/20 SEAI Grant Funding/Private.
- TRL 6 EU Pilot: EU H2020 funding

- TRL7/8: NTMA - Irish Strategic Investment Fund and the Carlyle Group would be interested 'when progressed through the TRLs to commercial or near commercial stage'

1.6 Financial section

1.1.1 Definitions

Table 4. Definitions of the scope of each cost element

Type	Parameter	Definition
CAPEX	Project up to FID	Development and consenting work paid for by the developer up to the point of FID. Includes: · Environmental surveys: benthic, pelagic, ornithological, sea mammals, survey vessels, onshore surveys · Met station surveys: auxiliary systems; stable mounting structure for the sensors; wind, wind direction, temperature, pressure, humidity, solar radiation and visibility; · Seabed surveys: geophysical & geotechnical surveys and vessels · Coastal process surveys: impact on sedimentation and erosion of the coastline, determination of land-fall sites for power cable route selections. · Human impact studies: visual & noise assessment, socio-economic impact · Pre-FEED and planning studies Excludes: • Any reservation payments to suppliers • Full FEED studies
	Project from FID to WCD	Includes: Wind & Wave: • Further site investigations and surveys after FID • Engineering (FEED) studies

		• Environmental monitoring during construction • Project management (work undertaken or contracted by the developer up to WCD) • Other administrative and professional services such as accountancy and legal advice • Any reservation payments to suppliers Wave (in addition to the above): • Hire or purchase of fabrication yard such as used for Thornton Bank construction • Cranage etc. Excludes: • Construction phase insurance • Suppliers own project management
	Construction phase insurance	Cover from start of construction until operation start. All construction risks & third party. Includes: · construction/erection all risks, including marine transit and cargo · (Contingent) Delay in start-up · Operational all risks property damage, including mechanical and electrical breakdown · (Contingent) Business interruption · Third party liability
	Wind turbines (excluding towers)	Turbine: Payment to wind turbine manufacturer for the supply of the nacelle and its subsystems, the blades and hub, and the turbine electrical systems to the point of connection to the array cables. Includes: • Delivery to nearest port to supplier • Warranty • Commissioning costs

		Excludes: • Tower • OMS costs • RD&D costs
	Wind turbine towers	Includes: • Payment to suppliers for the supply of the support the tower including secondary steelwork for fixing to platform • Delivery to nearest port to supplier • Warranty Excludes: • OMS costs • RD&D costs
	Platform incorporating wave devices	Includes: Manufacture and Assembly • Structural Design • Manufacture • Transportation • Craneage • Assembly/erection of structural steelwork • Painting, Corrosion protection, Anti-fouling Hull • Cost of concrete production • Reinforcement steel for pre/post tensioning and steel rebar • Epoxy waterproofing to ballast tanks • Connections to steel superstructure

		Superstructure • Cost of steel • Connections • Steel corrosion protection • Assembly cost Mooring • Cost of concrete production • Reinforcement steel for pre/post tensioning and steel rebar • Proprietary connection and tidal dashpot arrangement • Ballast Wave Energy Converters Payment to turbomachinery and generator manufacturer for the supply of the generators, components and subsystems, and the electrical systems to the point of connection to the export cables. Includes: • Electrical Generation and Power Conversion o Electrical Design o Manufacture/procurement/assembly: Generators, Transformers, Switch gear, o Control system, Design, Programming, Hardware, software, o Transportation, Craneage • Electrical Cabling o Cable Design o Manufacture/procurement: Cables, joints, fibre optic o Transportation, Craneage • OWC Power Take-off

		o Air driven pneumatic turbines o Air flow manifolding valves o Delivery to fabrication yard o Warranty o Commissioning costs Excludes: • OMS costs • RD&D costs
	Array cables	Includes: • Delivery to nearest port to supplier • Warranty Excludes: • OMS costs • RD&D costs
	Installation of turbines at quayside	Includes: • Health and Safety advice Certification • Craneage • Transportation of all from each supplier's nearest port to fabrication yard • Pre-assembly work completed at a construction port before the components are taken offshore including fixing of wind turbine tower to superstructure at nearshore location • Commissioning work for all but wind turbine (including snagging post WCD)
	Installation of platform	<u>WAVE:</u> Includes: • Health and Safety advice Certification • Craneage

		• Marker buoys/signage • Transportation from construction yard to deployment site • Commissioning work for all but pneumatic turbines (including snagging post WCD) <u>Combined:</u> Includes: • Health and Safety advice Certification • All installation work for moorings, chains, platform, support structures, turbines and array cables including OMS (Installation Vessels, Support Vessels, tugs, Safety Boats, Divers, Remote Operating Vehicles) • Scour protection (for mooring and cable array) • Subsea cable laying and subsea cable protection mats etc., as required Excludes: • Installation of offshore substation / transmission assets
	Transmission build	Includes: • Supply, cable laying, and construction of transmission assets from where array cables enter the offshore substation.
DECEX	Decommissioning	Includes: • Planning work and design of any additional equipment required • Removal of the platform and mooring to meet legal obligations • Includes further environmental work and monitoring • Recycling value of steel superstructure
OPEX	Operation and planned maintenance	Starts once first platform is commissioned. Includes: • Operational costs relating to the day-to-day control of the wind/wave array • Condition monitoring • Planned preventative maintenance, health and safety inspections
	Unplanned service	Starts once first platform is commissioned. Includes:

		• Reactive service in response to unplanned systems failure of any the wind turbine, wave power take-off or electrical systems.
	Operations phase insurance	Starts once first platform is commissioned, taking the form of a new operational “all risks” policy and issues such as: substation outages, design faults and collision risk become more significant as damages could result in wind/wave farm outage. Insurance during operation is typically renegotiated on an annual basis.
	Transmission charges	Includes: • Local grid operator transmission charges.
	OPEX Other	Fixed cost elements that are unaffected by technology innovations, including: • Contributions to community funds. • Monitoring of the local environmental impact of the wind/wave array.
AEP	Gross AEP	The gross AEP averaged over the wind/wave array life at output of the turbines. Excludes aerodynamic array losses, hydrodynamic array losses, electrical array losses and other losses. Includes any site air density adjustments from the standard turbine power curve for both the wind and the pneumatic turbines.
	Platform array availability	Energy production loss throughout the project life time due to unavailability of the platform array system. Accounts for improvements in early years and degradation in later years. Includes: • Availability of wind turbines, structure and array cables, accounting for scheduled and unscheduled downtime. • Availability of wave energy converters, accounting for scheduled and unscheduled downtime Excludes: • Transmission availability on substation and to shore and wider grid.
	Aerodynamic array losses	Typical wake losses within a 500MW wind farm, dependent on turbine rating. Applies to wind-generated energy only.
	Electrical array losses	Electrical array losses between the turbines and the offshore metering point for a typical wind/wave array.

		Excludes: transmission losses.
	Other losses	Lifetime energy loss from cut-in / cut-out hysteresis, power curve degradation, and power performance loss of both the wind and wave energy systems
	Net energy production	AEP averaged over the wind/wave array life at the offshore metering point at entry to offshore substation taking into account all losses

1.1.2 Assumptions

Baseline costs and the impact of innovations are based on the following assumptions.

1.1.3.1 Global assumptions

- Real (end-2015) prices
- Commodity prices fixed at the average for 2015
- Exchange rates fixed at the average for July 2016 (that is, for example, £1 = €1.18)
- Energy prices fixed at the current rate

1.1.3.2 Wind/Wave farm assumptions

General

The general assumptions are:

- A 20-platform energy farm
- One 8MW wind turbine per platform, yielding a total wind capacity installed of 160MW for the farm
- A total wave capacity of 16MW per platform, yielding a total wave instal capacity of 320MW for the farm
- Platforms are spaced at 4.2 rotor diameters (downwind - prevailing) and 3 rotor diameters (across-wind - prevailing) in a rectangle of area approx. 7 km^2
- A wind farm design is used that is certificated for an operational life of 20 years
- The lowest point of the rotor sweep is at least 22 metres above the platform superstructure
- The development and construction costs are funded entirely by the project developer, and
- A multi-contract approach is used to contract for construction.

Site conditions and meteorological regime

The site conditions and meteorological regime assumptions are:

- An average wind speed of 10m/s at 100m with a wind shear exponent of 0.12
- Rayleigh wind speed distribution

- A probability of sea-states to match that of the North Atlantic described in British Marine Technology "Global Wave Statistics"
- A mean annual average temperature of 10°C
- The average water depth at the site is 80 metres
- A tidal range of 4m at the site, and
- No storm surge is considered.

Turbine

The turbine assumptions are:

- The turbine is certified to Class IA to international offshore wind turbine design standard IEC 61400-3
- The baseline turbine has a three-bladed upwind configuration with a , planetary gearbox, , a medium speed permanent magnet generator, an output of 6,600V, and an operational interval of 4.8 to 12.1 rpm.
- The 8MW turbine has a 169m diameter, and a power density of 2.64 m^2/kW.

Support structure

The support structure assumptions are:

- A truncated wind turbine tower is mounted onto the superstructure of the platform above the mooring connection
- The tower is of sufficient height to ensure a minimum clearance of the low point of the rotor sweep of 22 metres above the superstructure.

Array Cables

- The array cable assumption is that a three core 33kV AC on fully flexible strings is used, that is, with provision to isolate an individual turbine.

Installation

The installation assumptions are:

- The platform modules are assembled into platforms in a benign, nearshore environment.
- Each leg of a platform is assembled in turn, with steel units being laced over concrete modules.
- Once a floating platform is constructed, a wind turbine is installed on the superstructure prior to transport of an assembled platform to the deployment site.
- Prior to transport of a platform to the deployment site, the corresponding mooring is transported and positioned in place.
- Array cables are installed via J-tubes, with separate cable lay and survey and burial. Decommissioning reverses the assembly process to result in installation taking one year.

Cables cut off at a depth below the seabed, which is unlikely to lead to uncovering. Environmental monitoring is conducted at the end.

Operations, Maintenance and Service

OMS assumptions are:

- Transmission charges for use of system are incurred as OPEX (the build is incurred as CAPEX), and
- Access is by work boats and mother ships or accommodation platforms, while jack-ups are used for major component replacement.

1.1.3 Commercial

1.1.3.1 3rd commercial project cost breakdown

Table 5. Spend for each cost element.

Commercial scale after 2 commercial scale projects CúNaMara Floating Multiple-use Energy Harvesting Platform MUP with 8MW wind turbine and 16 off 0.5MW wave generators	
Spend item	**Spend (€million)**
Project Consenting and Development to FID	**90.2**
Project management from FID to WCD	**23.2**
Construction phase insurance	**25.4**
Wind turbines (exc. towers)	**227.5**
Wind turbine towers	**27.0**
Platform incorporating wave devices	**1,017.6**
Array cables	**28.8**
Installation of turbines at quayside	**10.2**
Installation of platform	**100.0**
Transmission build	**145.7**
Construction contingency	**160.6**
CAPEX	**1,856.4**
Operation, maintenance and service (planned & unplanned, figures relate to post-warranty cost)	**720.0**

Operating phase insurance	256.0
Transmission charges	113.3
OPEX	1,089.3
Decommissioning concrete hull	32.0
Decommissioning steel structures	16.0
DECEX	48.0

1.1.3.2 3rd commercial project results

Table 7. 3rd commercial project results.

Commercial scale after 2 commercial scale projects CúNaMara Floating Multiple-use Energy Harvesting Platform MUP with 8MW wind turbine and 16 off 0.5MW wave generators		
Item	Value	Unit
Project rating, FLW_WAV	480	MW
CAPEX	1856	€million
OPEX	1089	€million
DECEX	48	€million
Cost of finance	2562	€million
Energy generated (wind)	13624	GWh
Energy generated (wave)	17400	GWh
Electricity price (wind)	236.6	€/MWh

Electricity price (wave)	**312.7**	**€/MWh**
Levelised cost, FLW_WAV	**178.10**	**€/MWh**
Levelised cost, FLW_WAV	**64%**	**-**
Simple payback	**4.9**	**years**
Discount rate or WACC	**8.9%**	**-**
Operating for	**20.0**	**years**
Payback	**7.6**	**years**
NPV (yr -4)	**942.2**	**€million**
NPV (yr 0)	**1443.0**	**€million**
NPV (yr 0) / CAPEX	**78%**	**-**
IRR	**16.4%**	**-**
Spatial IRR	**2.35%**	**% / km²**
Annual jobs	**457.1**	**FTE / year**
Annual spatial jobs	**65.3**	**FTE / year / km²**

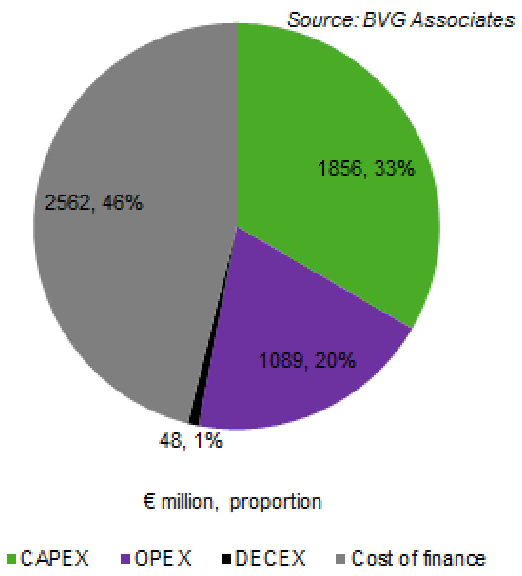

Figure 4. Breakdown of 3rd Commercial project expenditure (€ million).

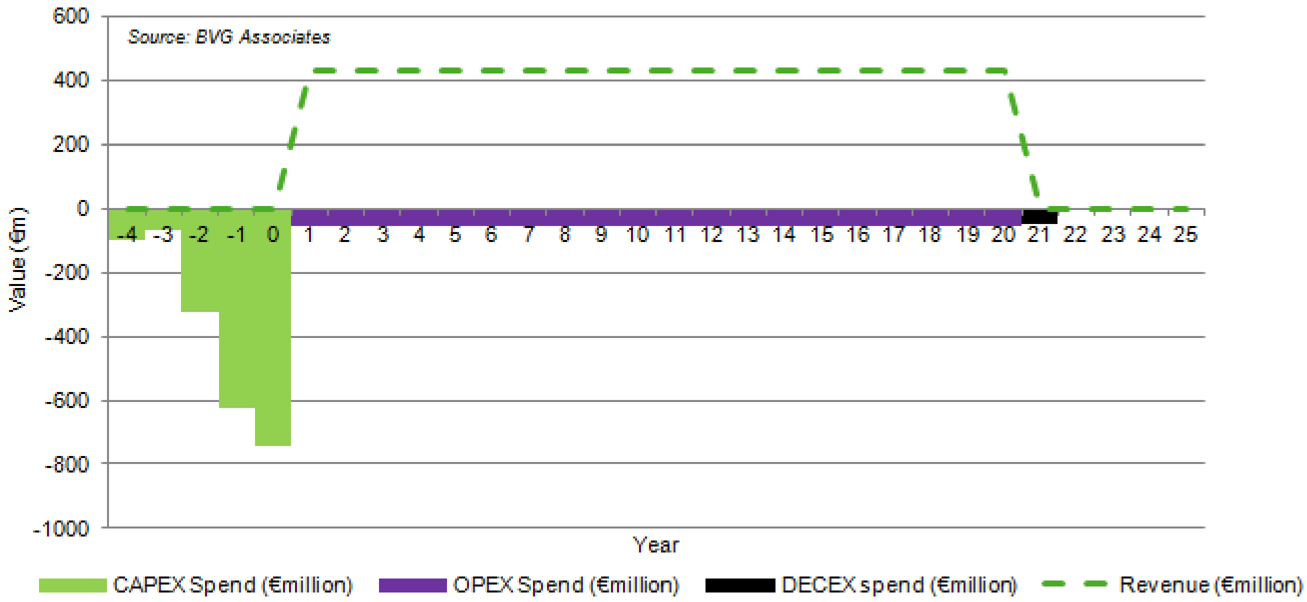

Figure 5. Spend cash flow of 3rd Commercial project expenditure (€ million).

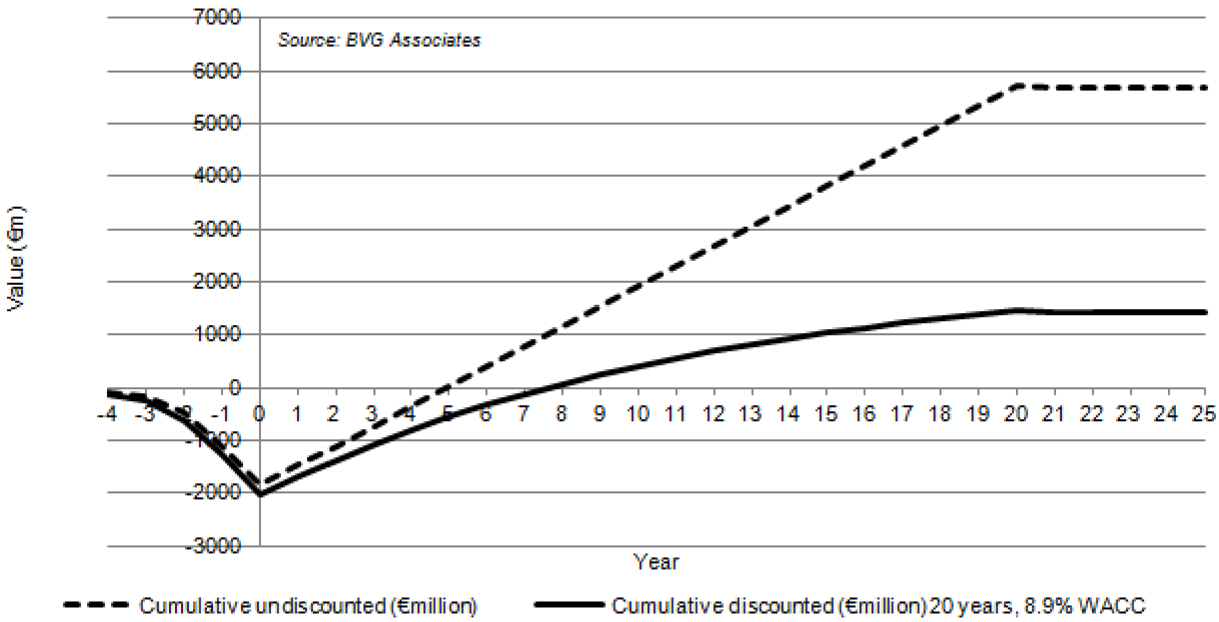

Figure 6. Cumulative cash flow of 3rd Commercial project.

1.1.3.3 Sensitivity

Table 8. Result of different variations in input.

Inputs				Outputs			
CAPEX	OPEX	Outpu	Price	Levelised	IRR	NPV (yr0)	Levelised
10%	0%	0%	0%	68.9%	14.9%	1239.9	8.0%
5%	0%	0%	0%	66.3%	15.7%	1341.4	4.0%
0%	0%	0%	0%	63.8%	16.4%	1443.0	0.0%
-5%	0%	0%	0%	61.2%	17.3%	1544.5	-4.0%
-10%	0%	0%	0%	58.7%	18.2%	1646.1	-8.0%
0%	10%	0%	0%	65.0%	16.2%	1392.9	2.0%
0%	5%	0%	0%	64.4%	16.3%	1418.0	1.0%
0%	0%	0%	0%	63.8%	16.4%	1443.0	0.0%
0%	-5%	0%	0%	63.1%	16.5%	1468.0	-1.0%
0%	-10%	0%	0%	62.5%	16.7%	1493.1	-2.0%
0%	0%	10%	0%	58.0%	18.2%	1841.3	-9.1%
0%	0%	5%	0%	60.7%	17.3%	1642.1	-4.8%
0%	0%	0%	0%	63.8%	16.4%	1443.0	0.0%
0%	0%	-5%	0%	67.1%	15.5%	1243.8	5.3%
0%	0%	-10%	0%	70.9%	14.5%	1044.7	11.1%
0%	0%	0%	10%	58.0%	18.2%	1841.3	-9.1%
0%	0%	0%	5%	60.7%	17.3%	1642.1	-4.8%
0%	0%	0%	0%	63.8%	16.4%	1443.0	0.0%
0%	0%	0%	-5%	67.1%	15.5%	1243.8	5.3%
0%	0%	0%	-10%	70.9%	14.5%	1044.7	11.1%

1.1.4 Pilot

1.1.3.1 Pilot project cost breakdown

Table 9. Spend for each cost element.

1/4 scale 'EU pilot' *Wind: A representative system to simulate key features of a wind turbine* *WECs: Nose-piece platform footprint of approx. 26m X 13m with eight 31.25kW OWCs chambers at 1:4 scale*	
Spend item	**Spend (€million)**
Construction phase insurance (2 years)	0.08
Reinforced concrete shell and core (38m X 19m)	1.26
Conideck - Epoxy membrane sealant (750 m^2)	0.04
Steel for super structure (40 tonnes/unit x 2 units) and fittings	0.23
Valves	0.40
Turbines	1.00
Instrumentation	0.05
Wind Analogue	1.00
Construction yard/synchrolift/craneage storage (25 % of construction and material costs)	0.37
Transport from ship yard to test site (16 days)	0.05
Mooring	0.15
Construction contingency (25% of all costs)	1.46
CAPEX	**6.09**

Operation, maintenance and service at SmartBay test site (1 year)	0.37
Staff (total 3 people for 3 yrs)	1.05
OPEX	**1.42**
DECEX item 1: Removal (12 days)	0.04
DECEX item 2: Recycling (15% cost value)	-0.25
DECEX	**-0.21**
TOTAL ESTIMATED COST	**7.30**

1.1.3.2 Gap In Finance for Pilot

This early TRL pilot will require a grant of at least approximately €7.30 million for NPV to be 0.

1.7 Risk section

1.1.1 Commercial Risk Analysis

1.1.3.1 Hazards description

- 100 Hazards identified under six categories: 1. Operation - all stages, 2. Economic and Political, 3. Financial, 4. Environment, 5. Socio-economic, 6. Health and Safety.
- Hazards were colour coded (risk matrix 1-25) depending on risk magnitude revealing
  - **28 High (red)**,
  - **59 Medium (orange)** and
  - **13 Low (green)**.
- Issues and causes described for each hazard, including the effect (-/+) of multiple industry and technology co-location.
- A ranking (1-5) used to quantify Consequence and Likelihood with resultant risk magnitude for each hazard.
- Risk response strategy proposed and residual risk magnitude quantified for each hazard.

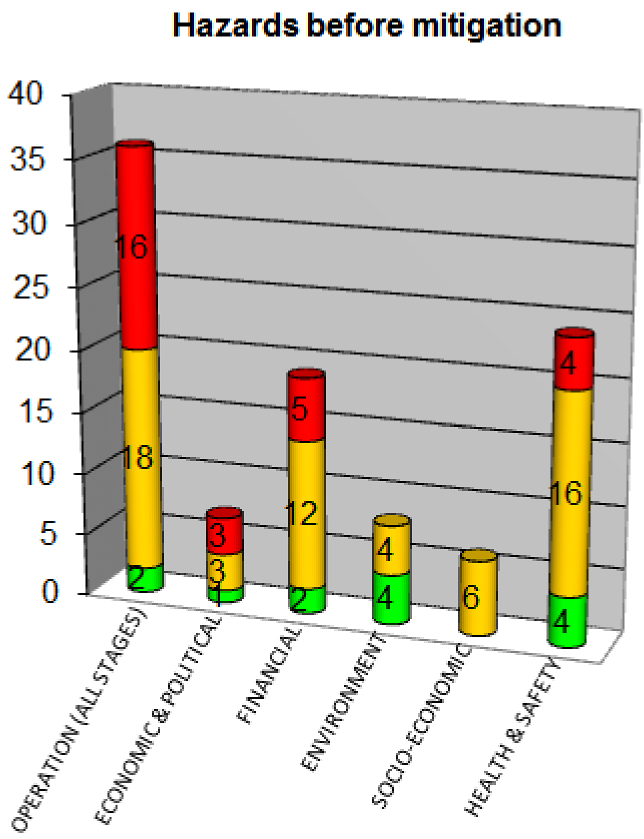

Figure 9: Hazards before mitigation

1.1.3.2 High risk (red) hazards identified before mitigation

Table 11: Identified Hazards

Hazard Category		Issue	Sum
1. Operation (all stages)	Pre-construction	Site Problems and Licensing	2
		Technical Risk	2
		Insurance	2
	Construction	Weather conditions	1
	Operational	Component/System failure	1
		Component/System Accidental Damage	1
		Pollution	1
		Maintenance and logistics Issues	1
		Health & Safety	1
		Emergency response	1
	Decommissioning	Device Removal	2
		Environmental impacts	1
2. Economic and Political	Public sector support	Grants and subsidies	1
		Applied price forecast	1
	Market dynamics	Commodity prices, currency fluctuations, inflation	1
3. Financial	Investor financial support	Lack of investment	5
4. Environment			0
5. Socio-economics			0
6. Health and Safety	Ergonomics	Injury due to user interaction with system	1

	Ports and Mobilisation	**Injury during port operations**	**1**
	Subsea Operations	**Injury to divers during subsea operations**	**1**
	Working at Height	**Injury caused while tasks being performed at height**	**1**
		Total	**28**

1.1.3.3 Commercial High Risk Response

Operation (all stages)

Description: The Operational risks account for approximately 57% of all red-category risks identified. "Site problems and licensing" issues relate to site compliance from environmental perspective, and granting of licence process at the site of interest. Insurance issues may be encountered due to the perceived increased complexity and unproven nature of technology combination. These risks may result in delays, higher costs and even project failure at the pre-construction stage of the project.

Risk response: Risk avoidance strategy will include employing competent and experienced environmental manager and team and pre-plan as early as possible for a thorough EIA study.

The company will have plans in place to mitigate against delays associated with licensing process which as understood is likely to fall within a statutory timeframe. The experience gained during the pilot and early commercial projects in this field will be highly beneficial.

Insurance risks will be tackled by liaising closely with the insurance industry from the pilot and early commercial stages to ensure that the sector's requirements are fully understood. The technology will be validated further with the early commercial project as post-prototypical, which is expected to secure affordable insurance rates for the fully commercial deployment.

Description: During construction phase adverse weather conditions may prevent access, increase downtime and shorten construction time windows. This could result in delays and higher costs.

Risk response: The CúNaMara floating-modular design offers risk avoidance by allowing for construction and partial assembly to be undertaken at shore in a purpose built dry basin within a fabrication yard, that transforms to a wet basin and opens to the sea allowing the modules to be towed to location. The planned deployment should coincide with the summer months to reduce the risk magnitude even further as the likelihood of harsh weather conditions is lessened.

The adverse weather risk is mitigated as the manufacturing/assembly site will be at close proximity to deployment location which reduces the risk of running into bad weather. Deploying from a site that has access to an established supply chain of experienced contractors including specialist vessel operators will mitigate the risk.

Description: At operational stage the biggest risks are associated with failure at component or systems. Some components originate from onshore operations or different offshore industries. Optimisation and tailoring for their intended use in the marine environment will allow them to be trialled during pilot and early commercial stage, however more failures than normal may result in the long term (e.g. survivability, reliability, fatigue, fouling, corrosion, weakening of structures). Component failures may present themselves during extreme weather conditions (e.g. mooring failure). Bad weather may also increase downtime and shorten maintenance time windows. The consequence of the above risks is less revenue generated, redesign efforts, higher costs and project failure if not addressed appropriately.

Risk response: Complete failure mode and effect analysis of all components will be undertaken so that all failures will be properly understood. Extensive testing will be undertaken at component and system level with capabilities already identified in Ireland. The results will be validated during pilot and early commercial deployments. The experience and resources (vessels) from other mature offshore sectors will be exploited to help reduce potential downtime due to weather.

Moorings extensive testing will prove the novel gravity-based technology which is currently on trial which will reduce the risks associated with this particular component.

Description: At operational stage pollution, health and safety and emergency response issues that may arise could result in injured personnel/subcontractors, seizing power production, higher costs and delays.

- At extreme circumstances pollution (e.g. from leaked chemicals) from wind/wave components could destroy or contaminate fish populations affecting different industries resulting in liable losses.
- Low skilled or inexperienced workforce, failing to comply with H&S regulations/guidelines could result in injured personnel.
- Distance of site from emergency response and increased offshore activity will increase (risk for) incidents and therefore increased need for extra capacity (i.e. more pressure) on emergency response services at national level.

Risk response: Insurance cover will transfer the aforementioned risks while the insurance sector involvement will ensure that the risk response measures are adequate for the scale of the intended operation.

Employing an experienced environmental manager and team and monitoring of population and movement in surrounding waters to the commercial farm will ensure enough reaction time is available to industries.

Health and safety strategy will include employing experienced H&S manager and team who will be in charge of ensuring high awareness regarding offshore H&S issues and that personnel are adequately trained. Transfer of skills from other established offshore oil & gas and port/shipbuilding sectors will be also beneficial.

The proximity of the deployment site from emergency response station at shore will help mitigate the relevant risk identified. Development and implementation of in-house Emergency Response and Cooperation Plan (ERCoP) will define the response of all parties involved in foreseeable emergencies. This will be carried out in cooperation with the authority responsible for the provision of response procedures designed to deal with any emergency at sea.

Description: During decommissioning, a risk associated with the sector infancy and the lack of experience with the process coupled to potential changes in the decommissioning responsibility/process (politically driven) could result in higher costs or fines. Removal of marine structures may result in pollution and disturbance of established habitats on the structures. Specifically, removal of moorings may present a higher risk.

Risk response: Standard procedures for the removal of offshore marine structures will be followed. The design allows conducting dis-assembly of device segment by segment and towing to a shore-based decommissioning site and consequently no specialist vessels will be required to meet the decommissioning needs of the commercial deployment. It is expected that the experience of the offshore oil & gas and offshore wind sectors will be beneficial. Funds for the decommissioning have been costed into the project budget.

Mooring may be a possible problem during decommissioning. Adequate contingency funds will be allocated and the possibility to allow the mooring to be left behind will be examined with the relevant authorities following a navigational risk assessment.

Economic and Political

Description: Potential issues identified under "public sector support" and "market dynamics" subcategories. Change of policy direction and appetite for renewables, conditions of FiT eligibility criteria, value and period could affect the financial projections. Other factors identified that can result in higher costs and/or lower revenue comprises poor sensitivity analyses, exposure to market risk and high inflation/currency fluctuations. These that can impact on value of cash flows relative to up-front investments and consequently result on higher costs and/or lower revenue generated.

Risk response: Accepting the above risks will include careful monitoring for possible escalations. The current trend dictates that the renewable energy sectors (including ocean energy) need to grow if national governments are to meet obligations around emissions, security of energy supply (85-90% of Ireland's energy is imported) and energy cost reduction. The Paris Climate Agreement has targets to combat climate change by carbon reduction which can only be met by reducing fossil fuels and increasing renewables and nuclear.

Business will be conducted in euros which is the local currency in Ireland. Experts will be consulted to maintain awareness of currency markets and reduce risk of adverse effect of commodity prices, inflation, etc.

Financial

Description: "Financial support" was identified as the subcategory where all red financial hazards are found. Potential issues around "financial support" could develop due to lack of (or removal of) investment which could be triggered due to a number of possible causes:

- Many wait-and-see investors do not invest due to risk of losing development costs and due to little benchmark data.
- Lack of experience and knowledge (i.e. Life cycle stage S0) may discourage the reluctant investors to assume unknown risks.
- First mover means that there is no established market and investors will need to create a market for the product
- wrong sensitivity analyses and price forecast; Bridge financing problems arise (e.g. from exposure to market changes); change of business climate; applied price forecast.

- Public sector support: unexpected phase-out or change of policy/terms/rules, delays in payment.
- Finance instruments related problems.
- Poor lending appetite from banks due to low economic climate.
- Lenders fail to comply with financial legislation/regulation (Basel III, Solvency II).

Risk response: First mover advantage captured in strong IP and patent portfolio will inspire investor confidence. In the absence of benchmark data, clearly demonstrable results from studies undertaken during pre-commercial TRL stages validated during Pilot and early commercial deployments will present sufficient data placing technology beyond prototypical stage. Flexibility to form Special Purpose Vehicle with partner/investor organisations will reduce financial risk exposure.

Maintaining a strong lobby of customers (i.e. national government) will help create correct market mechanisms/tax schemes and de-risk the sector. Joining forces with internationally recognised organisations and forums (e.g. Ocean Energy Europe) will intensify the process as the need for growth in ocean energy industry will enable governments to meet national obligations for reducing emissions, improving security of supply and reducing cost of energy are the key driving forces.

HEALTH & SAFETY

Description: Red risk identified under several subcategories which could lead to personal injury including:

- Ergonomics (difficult to construct design; moving around system: slips, trips and falls; restricted movement: lack of space to access components; lifting: hoisting parts and tools into position)
- Ports and Mobilisation (vessel movements: collision; port operations: material handling, refuelling, waste disposal; unsuitable facilities: quayside loading limits)
- Subsea Operations (entrapment, falling objects, decompression sickness, use of tools underwater
- Working at Height (falls, dropped objects)

Risk response:

- Ergonomics
    - Rigorous safety plan for fabrication and construction which must be adhered to including preliminary safety plan including risk analysis from all designers.
    - Fully resourced, site specific construction safety plan including programme for the works
    - Independent onsite safety team with marine safety experience
    - Regular independent equipment inspections
- Ports and Mobilisation
    - Port traffic management plan enforced by harbour master.
    - Adequate site safety plan
    - In-port medical facility including medical helicopter for emergency evacuation
    - Warning notices re loading limits clearly visible and communicated
- Subsea Operations
    - Minor requirement for divers to be met using fully certified, reputable dive company with accident free track record are used.
    - Ensure this company produces and complies with high level safety plan for the work being undertaken
- Working at Height

- All work to take account of the principles of prevention in relation to working at height. Risks to be taken account of and mitigated against in safety plan for the project.
- All workers to undergo certified working at height training.
- Safety cages to be installed around all ladders
- Fall arrest systems (harness etc) to be employed in all risk areas.

1.1.2 Pilot Risk Analysis

1.1.3.1 Pilot High Risk Response

A total of nineteen red risks for the pilot project have been identified, thirteen Operation, one Economic and Political, one Financial and four Health and Safety.

Operation (all stages)

The Operational risks account for the majority of the red-category risks identified.

Description: A Site problems and licensing issue relates to the length of time it may take to obtain any licences required to deploy the pilot. Insurance costs for the pilot may be prohibitively high. While it is expected that insurance will be available, the experimental nature of the pilot may deter some insurers, potentially resulting in cost overruns and delays.

Risk response: The Company will have plans in place to mitigate against delays associated with licensing process which as understood is likely to fall within a statutory timeframe. Insurance risks will be mitigated by liaising closely with the insurance industry in advance of commencement of the Pilot to ensure that the sector's requirements are fully understood and met.

Description: Potential technical-based issues during operation include results from earlier TRL testing showing that the platform is not suitable for the inclusion of offshore wind. Such tests may also bring into question the suitability of incorporating oscillating water columns into the hull of the platform. Should these risks materialise, they would result in project failure.

Risk response: In order to mitigate these risks, the Company intends to complete as much computational modelling - including CFD/CAD modelling - as possible to fully understand technology at an early stage. Extensive use of tank testing to include wind power analogues will ensure the suitability of the platform for both the wind and wave technologies.

Description: During the operational phase, and as with any new technology, the risk of component failure must be addressed. Such failure would include technologies transferred from an onshore to an offshore environment. Most impactful of all failures would be a failure of the mooring system. Weather conditions may reduce weather windows during which maintenance and repair may be carried out, introducing delays to the project.

Risk response: The Company will undertake a complete failure mode and effect analysis of all components so that all failures will be properly understood prior to deployment of the Pilot. Extensive testing at component and system level will take place. Downtime may be reduced by deploying experience and resources (vessels) from other mature offshore sectors. The innovative mooring system will be extensively tested and modelled (numerically and at scale in wave tanks). Existing gravity-based mooring foundation research will help reduce this risk

Description: Some pilot specific risks arise from use of a third party test facility. It is planned to use the SmartBay test facility located in Galway, Ireland. Risks include lack of suitable equipment at the test facility, which to date has only tested smaller devices. Changes in public policy, both at national and European level, could endanger the future of the test facility, potentially introducing access issues to the site. Lack of local road access for large vehicle required to transport components of the pilot project is also a risk.

Risk response: The Company is a member of a number of lobby groups. Through ongoing engagement with these groups and between these groups and national/European bodies, the importance strategically and environmentally and for research test facilities such as SmartBay can be highlighted to ensure the continued funding and operation of such sites.

Description: A number of third party manufacturers will be required for the project, for example to manufacture pneumatic turbines, air control valves etc. Dependence on such third parties introduces the risk of cost overruns and delays to the project.

Risk response: The Company will identify third party manufacturers at an early stage and engage with these companies throughout the pilot development phase to ensure supply and reduce the risk of delays

Description: The risk of pollutants to the environment during the construction, operation and decommissioning phases must also be addressed.

Risk response: The Company will employ experienced environmental manager with knowledge of ocean energy issues. In order to reduce the impact on the environment throughout the lifetime of the project, the company will carry out a thorough investigation including EIS for careful site selection. During all phases, the quality of surrounding waters will be monitored to ensure enough reaction time is available to other industries such as aquaculture. The Company will make use of and learn from the experience of the offshore oil and gas and offshore wind sectors.

Only proven technology (or technology with acceptable adverse effects levels) will be used and a strict chemical management programme for both wind and wave systems will be enforced. This will focus primarily on lubricants, and standard leak containment systems will be used. The possibility for developing biodiversity offsets to achieve no net loss of species, community structure, habitat integrity, ecosystem functioning etc will be explored.

During the decommissioning phase, the Company will limit the environmental risk by follow standard procedures for the removal of offshore marine structures.

Economic and Political

Description: A single Pilot-specific Economic and Political red risk has been identified. This risk has also been identified as a Financial Risk. The pilot project is dependent on public mechanisms for funding. Changes to national and European policies with respect to grant aid of and subsidies to offshore-energy development projects may take the form of changes to the conditions of the funding, eligibility for the funding or changes to the duration of the funding. Such risks endanger the financing of the project and may also introduce delays.

Risk response: At this time, the Company believes that the need for growth economically and the continually increasing demand for energy will negate the risk of removal or phase-out of subsidies. Europe needs renewable energy to reduce greenhouse gas emissions, ensure security of energy supply and stabilise energy prices. This will need to include ocean energy in order to provide aggregation of supply and reduce the need for storage. Ireland is a case in point with 85-90% of energy needs being imported. Environmental issues are being driven by national and international agreements such as the Paris Agreement to reduce carbon and mitigate climate change. This need for growth in the renewable energy sector will negate the risk of removal or phase-out of subsidies.

The company will ensure adequate funding is in place prior to commencing full scale construction

Health and Safety

The same Health and Safety risks have been identified for the third commercial. These risks are somewhat lessened as the project is at a smaller scale, but exist nonetheless.