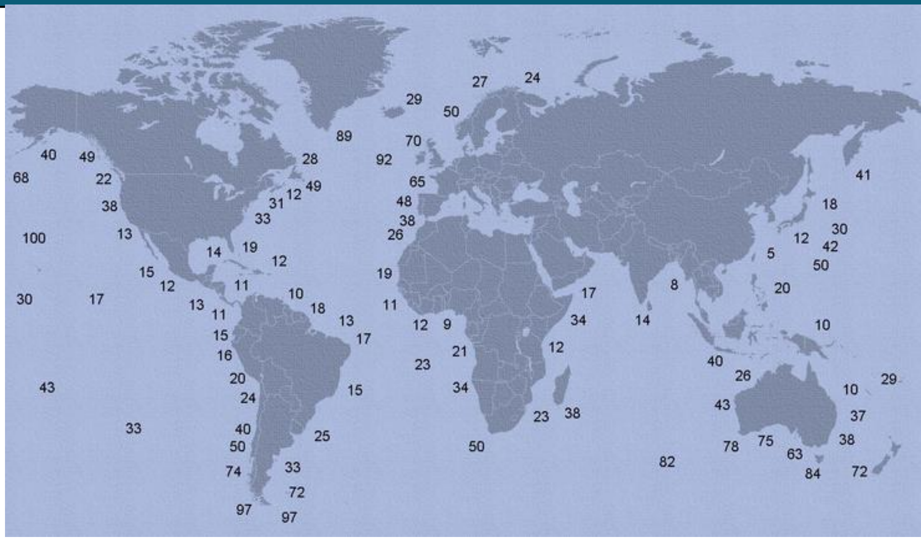
Pelamis - Care of the Marine Environment from concept through to implementation.

Andrew Scott – Business & Project Development Manager

Why wave energy?



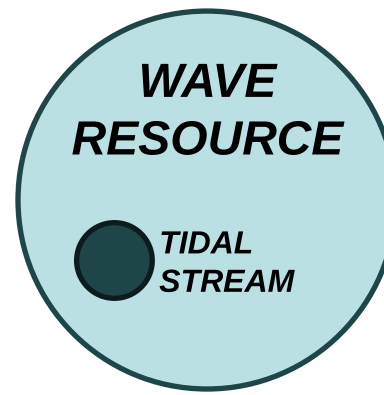
Ocean power conversion principles and theoretical global resource

	Description	Estimated global resource
Wave power	Surface and subsurface motion of the waves	8,000-80,000 TWh/year
Ocean thermal energy	Uses the temperature differential between cold water from the deep ocean and warm surface water	10,000 TWh/year
Osmotic energy	Pressure differential between salt and fresh water	2,000 TWh/year
Tidal energy	Hydrokinetic energy that harvests the energy of ocean currents and tides	800 TWh/year

Source: Intergovernmental Panel on Climate Change, 2008

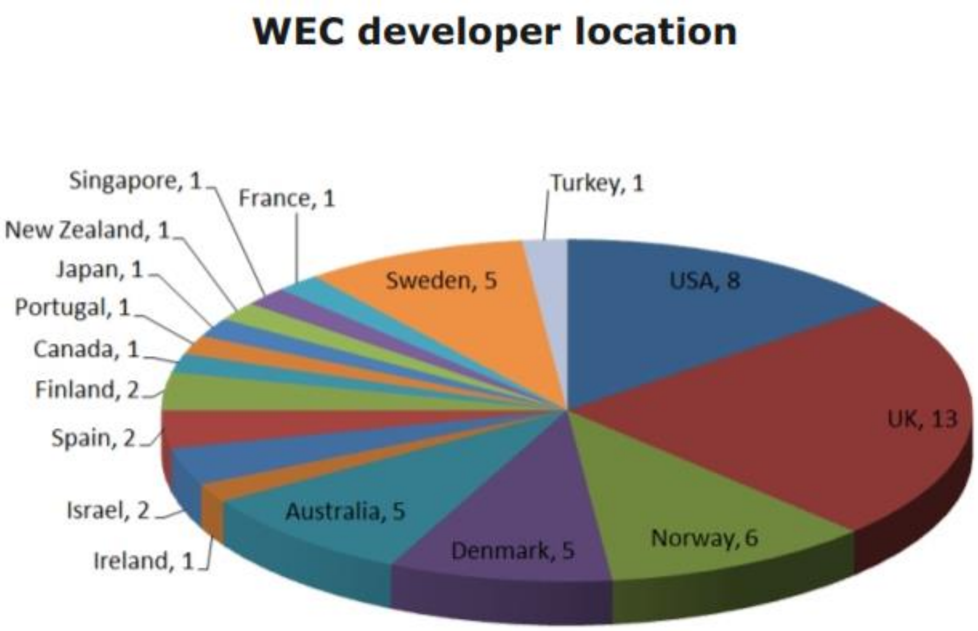
- Potential to contribute up to 10-15% electricity demand in countries like UK - security of supply advantages.
- Forecastable – stored wind energy.
- Fewer spatial constraints so projects can become large.
- Dense resource, not ‘diffuse’ like solar, wind, hydro etc.
- Minimum environmental and visual impact, ‘out of sight, out of mind’: low carbon/renewable source of energy.

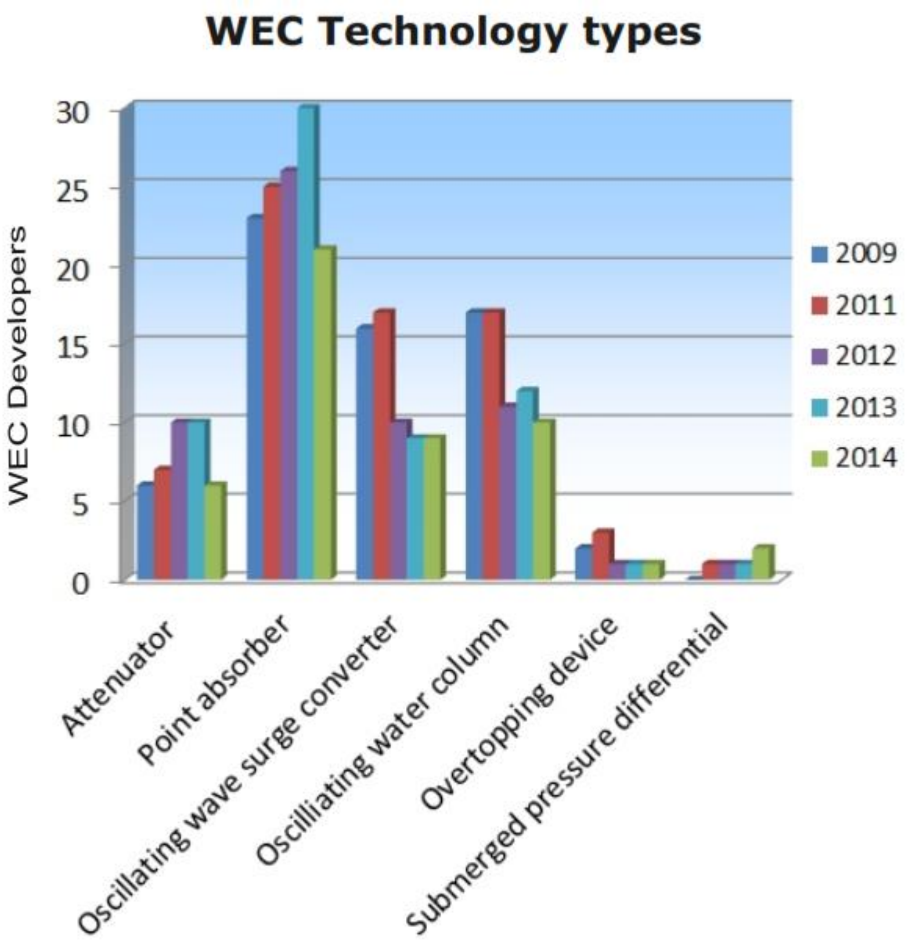
- Significant economic opportunity (equal to or greater than current global wind sector.
- Significant industrial opportunity.



pelamis wave power

WEC Technology Developers



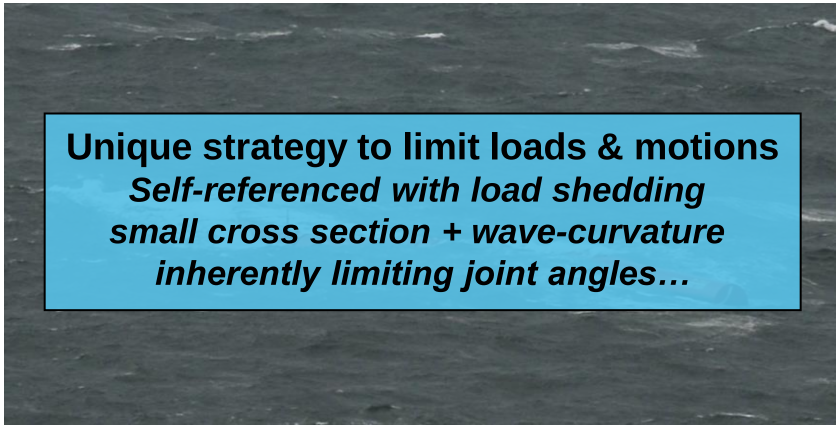


Pelamis Wave Power - Introduction

- Company incorporated in 1998 and based in Edinburgh throughout.
- ~50 full time staff with expertise in structural, electrical, mechanical, electronic, and software engineering, numerical modelling, wave resource modelling, manufacturing, offshore operations, research, management, sales & finance.
- Minimal outsourcing: In-house R & D, design, assembly, trials, subsea infrastructure construction, marine operations and machine operation.
- Recognised worldwide as the leading wave energy technology developer.

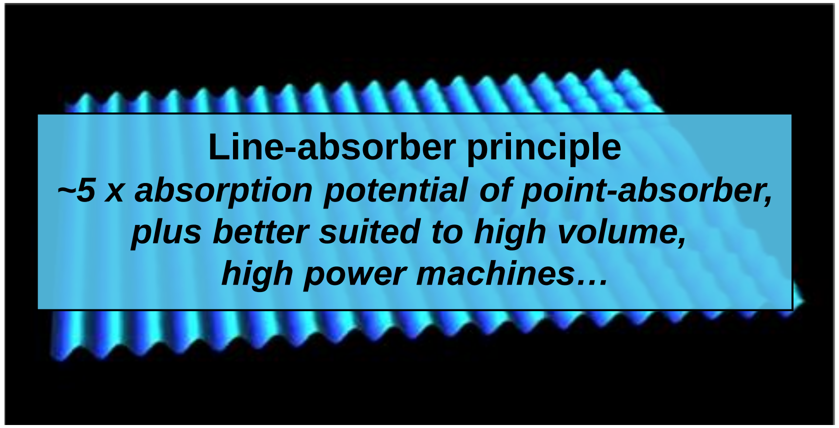
PELAMIS WEC – Fundamental Principles

Survivability principles



Unique strategy to limit loads & motions
Self-referenced with load shedding small cross section + wave-curvature inherently limiting joint angles…

Absorption principles

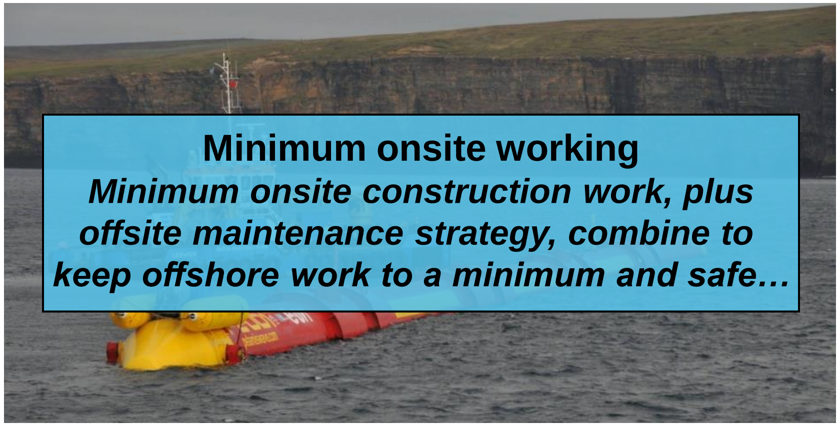


Line-absorber principle
~5 x absorption potential of point-absorber, plus better suited to high volume, high power machines…

Engineering embodiment

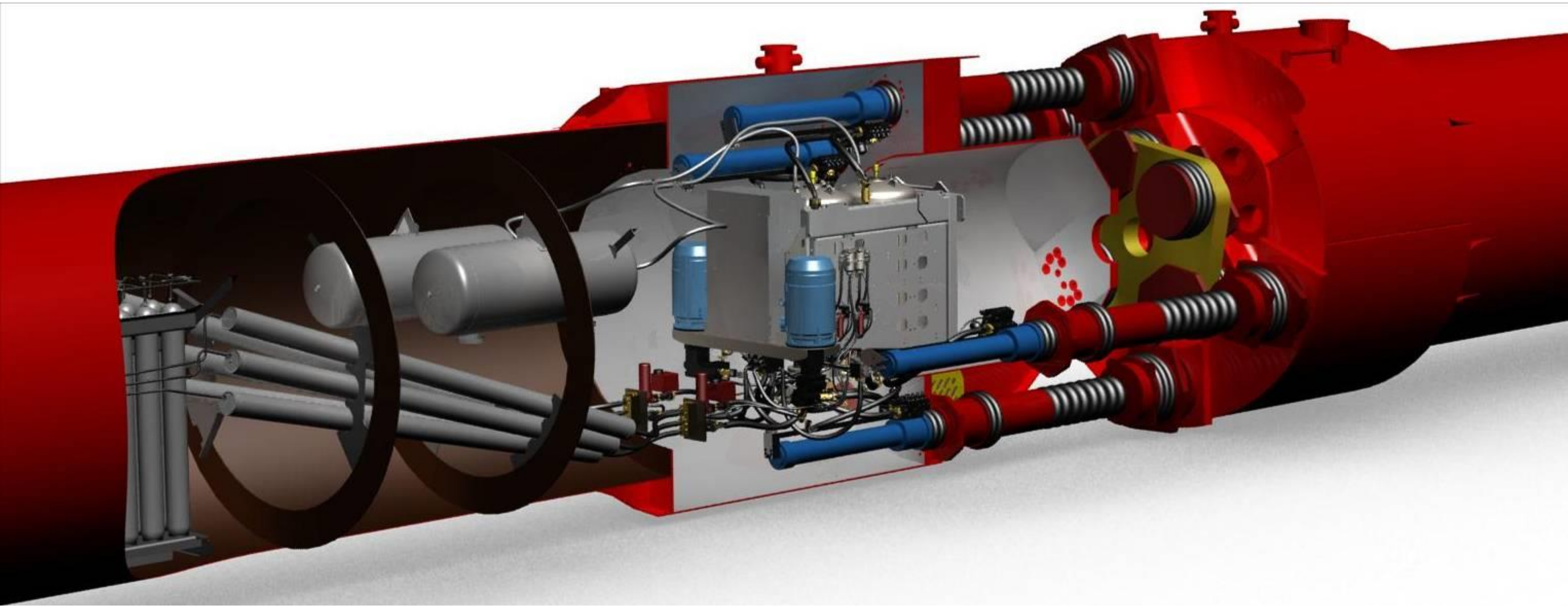
Efficient, available, patented technology
Selectable, tuneable resonant response enables line-absorber concept, plus high conversion efficiency PTO demonstrated…

Construction and O&M strategy



Minimum onsite working
Minimum onsite construction work, plus offsite maintenance strategy, combine to keep offshore work to a minimum and safe…

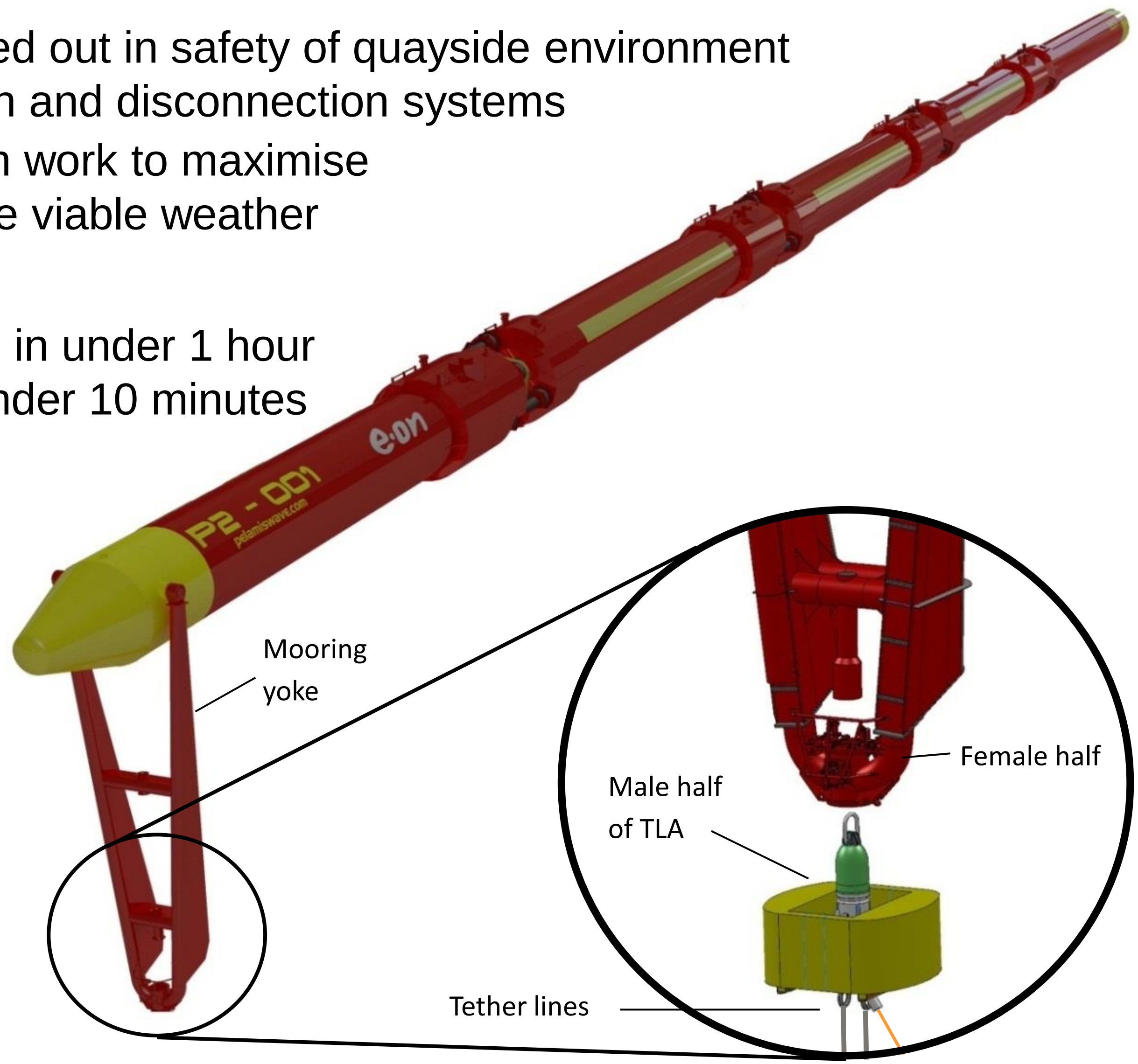
'Available', Efficient, Electro-hydraulic PTO



- Hydraulic cylinders resist joint motion
- Control manifolds direct oil flow from rams directly to/from high pressure storage
- High pressure gas accumulators provide energy storage between wave groups
- Generation via variable displacement motor gives smooth power out
- Minimum of two barriers between hydraulic fluids and external environment

Pelamis O&M strategy & TLA Connection

- Maintenance carried out in safety of quayside environment
- Remote connection and disconnection systems
- Minimum hands-on work to maximise safety and increase viable weather conditions
- Fastest installation in under 1 hour
- Fastest removal under 10 minutes



pelamis wave power

Addressing Survivability Risks in an Emerging Industry

- How do tackle this in a new industry where classification codes and standards do not yet exist?
- In established industries such as oil and gas and marine, classification provides assurance of risk management to many other stakeholders as well as the client or operator, e.g. insurance underwriters, MCA etc.
- The marine energy industries must do the same but the codes do not yet exist and the devices in development, especially WECs are very diverse.
- PWP chose to conduct a design verification exercise focussing on survivability during the design of the first full scale prototype and engaged a reputable global consultancy with extensive experience in the offshore oil and gas industry as the suitably qualified and independent review body.
- PWP has played an industry leading role since then, both by example of thorough implementation of this and by involvement in the development of guidelines and recommended practices in this area.

Independent Third Party Verification

- The first verification followed the process of traditional classification, i.e. Trying to follow the most relevant codes from oil and gas directly.
- The current method is based on DNV's Recommended Practice RP-A-203 Qualification Procedures for New Technology, as developed by PWP and Atkins over recent years.
- The review process is based on a failure mode and effect analysis (FMEA). These sessions cover the main survivability risks to the installed machine, namely:
  - Foundering (i.e. mooring failure)
  - Catastrophic structural failure (e.g. machine breaking in two, from a fatigue crack)
  - Sinking (e.g. progressive flooding due to insufficient watertight subdivision)

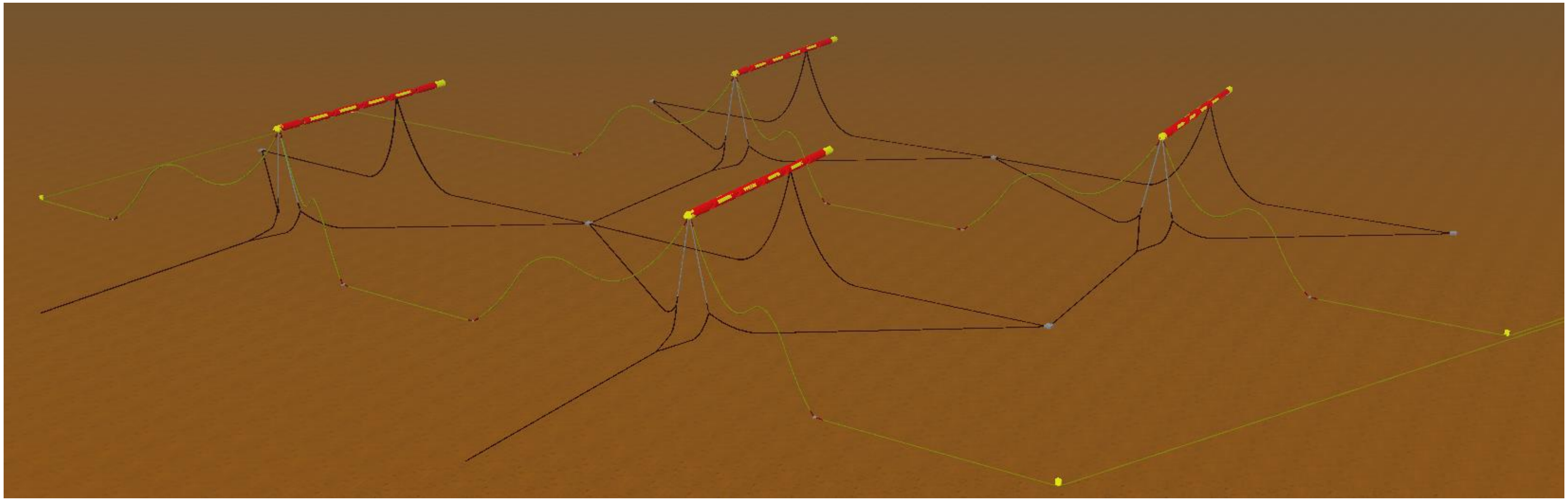
Use of FMECA to structure the process and focus effort

- Categorise components and failure types
- Define technology class - e.g. proven, refinement of existing part, new part
- Assess probability of failure – informed by analysis in line with codes and standards where applicable.
- Assess consequence and criticality of failure
- Use the overall risk to guide effort towards the areas of highest importance

	Component			Failure						Initial								
ID	ref	Location	Component/ sub-assembly	ref	Failure type	Initiating Event/Failure Mechanism	P2 to P1A IE/FM Relationship	Technology Detail	Technology Class	Probability	Consequence	Risk	Probability	Consequence	Justification	Mitigation	PWP Doc Ref	Meeting Notes
	1 2 3 4 5 6 7 8 9 10 11 12 13 14	Moorings TLA Yoke Nose Front/Mid/Rear Tube End-cap fabrications Main Joint Bearing system Ram rod bearing system Ram mid bearing system Module Power Take-off structure Rams Active Yaw system Tail		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	corrosion/material degradation wear mechanical failure (eg bolt loosening) fatigue (FLS) Ship Impacts Foreign Body Impact Systems failure generating ALS Malicious damage Environment generated ULS Machine generated ULS service fatigue/cyclic loads extreme service loads SLS accidental service loads Unable to repair. Unable to service							Very low Low Med High						
1.1	1	Moorings	Shackles	1	corrosion/material degradation	Shackle corrosion leading to line failure	Same	Same	1	1	3	V Low	Mooring inspection in Oct '09 showed minimual corrosion levels on PRT shackles. See chain corrosion comments below.	Most chain lines are backed up. Failure case simulations show strength of remaining equipment sufficient to prevent consequential failure. Loss of rear line may cause damage to umbilical.	0.3mm per year is inline with OS-E301, ch 2 sec 2 - Table E1 for components on the seabed and which are regularly inspected.	ROV inspection will take place regularly. Failure of one line immediately detected through GPS display of position relative to mooring centre, and joint offset	PWP report D-MG-30008	Issue mooring inspection report. Dyanamic analysis report & mooring design report. - Done
1.1	1	Moorings	Chain	1	corrosion/material degradation	Chain corrosion leading to line failure	Same	Same	1	1	3	V Low	Mooring inspection in Oct '09 showed minimal corrosion levels on PRT mooring chain after ~4 years exposure to seawater, well below the 0.3mm of reduction on chain diameter a year allowed for in strength calculations. Minimum safety factor 2 still achieved after 20 year corrosion allowance.	Most chain lines are backed up. Failure case simulations show strength of remaining equipment sufficient to prevent consequential failure. Loss of rear line may cause damage to umbilical.	0.3mm per year is inline with OS-E301, ch 2 sec 2 - Table E1 for components on the seabed and which are regularly inspected.	ROV inspection will take place regularly. Failure of one line immediately detected through GPS display of position relative to mooring centre, and joint offset	PWP report D-MG-30008	Issue mooring inspection report. Dyanamic analysis report & mooring design report. - Done
1.1	1	Moorings	Tether Hooks	1	corrosion/material degradation	Corrosion of tether hooks leading to seizure closed	New	Similar	3	3	2	Low	Most likely corrosion failure seizure the hook shut.	Unable to release hook resulting in difficulty in repairing/replacing synthetic tethers, TLA and umbilical. No risk to machine.				
1.1	1	Moorings	Tether Hooks	1	corrosion/material degradation	Corrosion of tether hooks leading to failure under load	New	Similar	3	1	3	V Low	Very conservatively designed - larger than surrounding components. See chain corrosion comments.	Failure of one hook will result in loss of one tether line - machine remains onstation and remaining line is rated for full load. Likely that remaining hook will undergo similar corrosion so limited time to remove machine => potential to lose machine.		ROV inspection will take place regularly. Failure of one line immediately detected through GPS display of position relative to mooring centre, and joint offset	PWP report D-MG-3A003	
1.1	1	Moorings	Tether Hooks	1	corrosion/material degradation	Corrosion of tether hooks leading to unintended release	New	Similar	3	1	3	V Low	4 x spring to close and lock gate. All parts of locking mechanism are stainless. Springs are SS. Gravity also holds gate shut. Needs to also have slack in the tether for the masterlink to fall out. This is only likely when the machine is not connected. Hooks are checked before every machine installation	Failure of one hook will result in loss of one tether line - machine remains onstation and remaining line is rated for full load. Likely that remaining hook will undergo similar corrosion so limited time to remove machine => potential to lose machine.		Hook would need to touch the seabed to release from tether line. Most unlikely since hooks are approx. 10m above the seabed in the still water condition. Known inspection point for ROV. Failure of one line immediately detected through GPS display of position relative to mooring centre, and joint offset	PWP report D-MG-3A003	
1.1	1	Moorings	Anchors	1	corrosion/material degradation	Corrosion of anchor structure leading to failure.	Same	Same	1	1	3	V Low	Mooring inspection in Oct '09 showed minimal corrosion levels on PRT anchors after ~4 years exposure at site. Anchors are burried lessening exposure to oxygen. However difficult to inspect. Anchors frequently used in offshore industry and corrosion is not a known failure mechanism.	Machine is still moored by chain and remaining front anchors as well as rear anchors.		Machine position is monitored and out of position motion would be immediately noticed (is alarmed). Recovery of machine would take place as soon as weather allowed.	PWP report D-MG-30008	
1.1	1	Moorings	Tethers	1	corrosion/material degradation	degradation due to UV and saltwater exposure	Same	Same	2	1	3	V Low	Tethers are polyester with good resistance to UV & seawater. Commonly used in the offshore environment. UV reduced by waterdepth.	2 x tether lines means there is redundancy. Both tethers are the same material so failure by degredation likely to effect both in a similar time scale.		ROV inspection will take place regularly. Failure of one line immediately detected through GPS display of position relative to mooring centre, and joint offset.		
1.1	1	Moorings	Wire Forerunners	1	corrosion/material degradation	Wire corrosion leading to line failure	Same	Same	2	1	3	V Low	Wire is selected inline with DNV OSE301 recommendations (ch2 sec 2 table E2). Likely to be buried => low corrosion but also that inspection not possible. Inspection of PRT 83mm wire onsite for 8 years showed as-new condition on opening and cleaning wire to individual strands (for new Speiler socket)	Anchor becomes detached on front line. Excursion range is increased provided mooring loads in that line exceed load required to drag chain through sand. Unlikely to drag any great distance and likely to move east presenting reduced risk to the umbilical.	OS-E301, ch 2 sec 2 Table E2. Load required to drag forward chains measured as 100Te during installation operations.		OS-E301, ch 2 sec 2 Table E2 PWP report D-MG-3A003	
1.1	1	Moorings	Joiner plates	1	corrosion/material degradation	Corrosion leading to failure	New	Similar	1	1	3	V Low	Mooring inspection in Oct '09 showed minimal corrosion levels on PRT joiner plates after ~4 years exposure. Plates are 110mm thick. See chain corrosion comments.	Failure of one line would not result in loss of machine.		Failure of one line immediately detected through GPS display of position relative to mooring centre, and joint offset.	PWP report D-MG-30008	Issue mooring inspection report. Done.
1.2	1	Moorings	Chain	2	wear	Chain wear leading to line failure.	Same	Same	1	1	4	Low	Wear calculations from PRT system indicated wear levels would likely be very small levels. Inspection of PRT has not shown any noticable wear but had limited operation.	Areas of most motion are backed up. Failure case simulations show strength of remaining equipment sufficient to prevent consequential failure.		Areas of high motion to be inspected with ROV requlariy.	PWP report D-MG-30008 PWP report D-MG-3A001 PWP report D-MG-3A003	Issue mooring inspection report. Dynamic analysis & mooring design report. Agreed that calculations are not necessary, in view of experience with P1a & PRT.

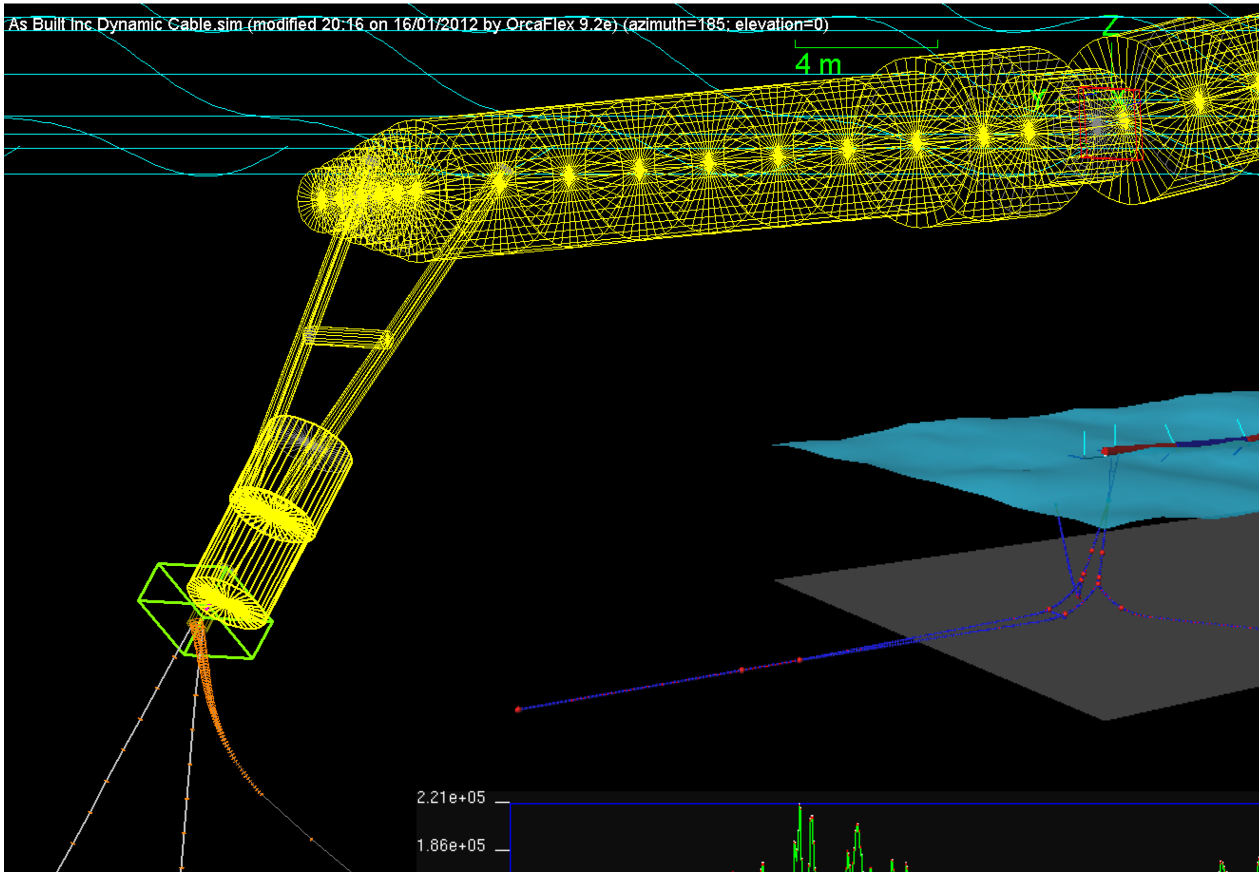
Thorough Assessment of Loading and Response

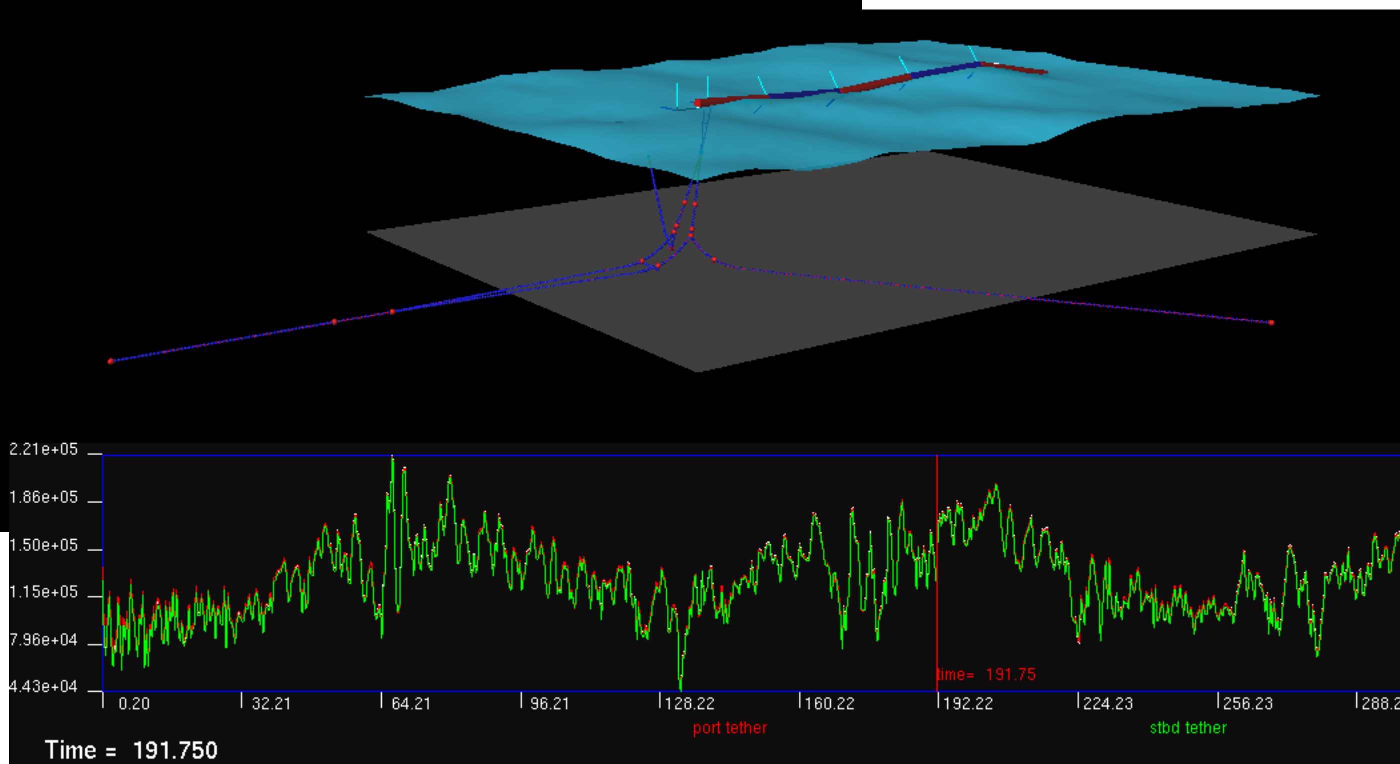
- ULS – Ultimate Limit State
  - Comprehensive load-case table to characterise environment
  - e.g.100year seastate with 10 year tidal current and wind driven current
- ALS – Accidental Limit State
  - E.g. Single line failure cases
- FLS – Fatigue Limit State
  - Also including consideration of corrosion and wear



OrcaFlex & PWP-PELs for Numerical Dynamic Analysis

Numerical models are checked against each other and against scale model tank-test results





pelamis wave power

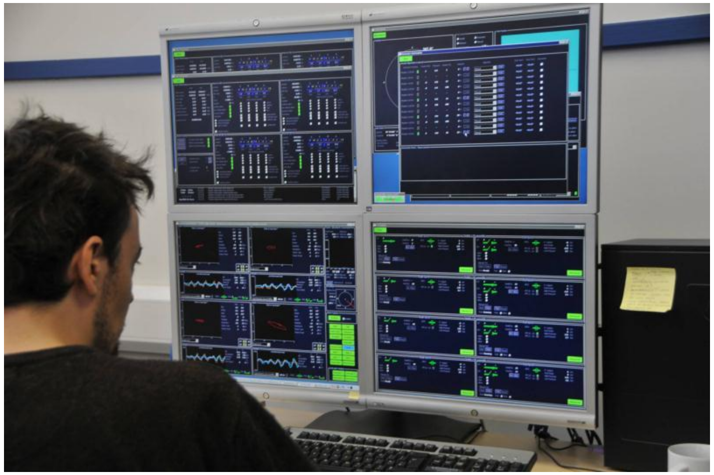
Making it real…

http://www.youtube.com/user/PelamisWavePower

pelamis wave power

Work-Up Programme

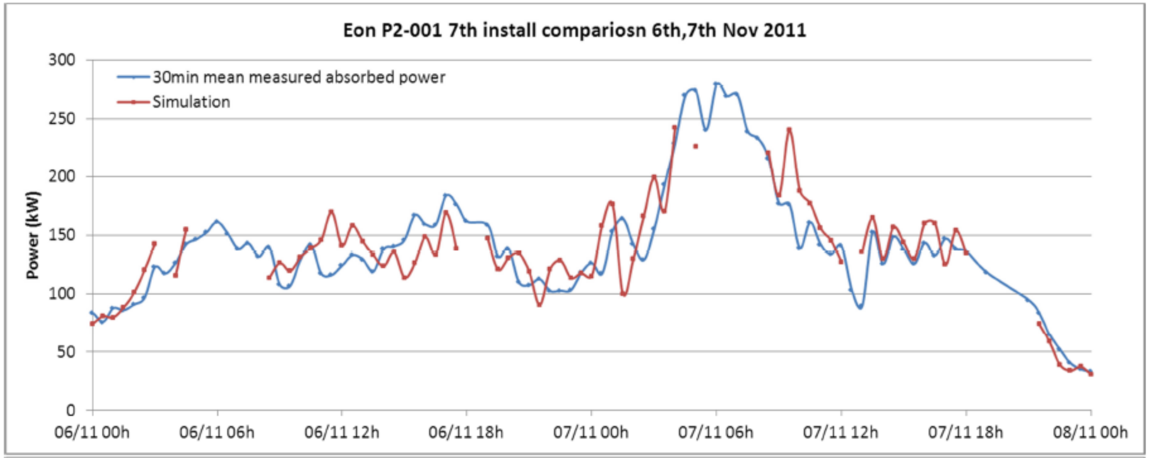
- Risk reflective testing and demonstration philosophy. [Not deploy and hope!]
- Full time engineering monitoring of all machine diagnostic signals to analyse trends, behaviour and identify system and component reliability.
- Machine cleared in step-wise process for gradual increase in operational conditions.
- Paralleled with detailed full system “forensic” style inspection of key components and systems.

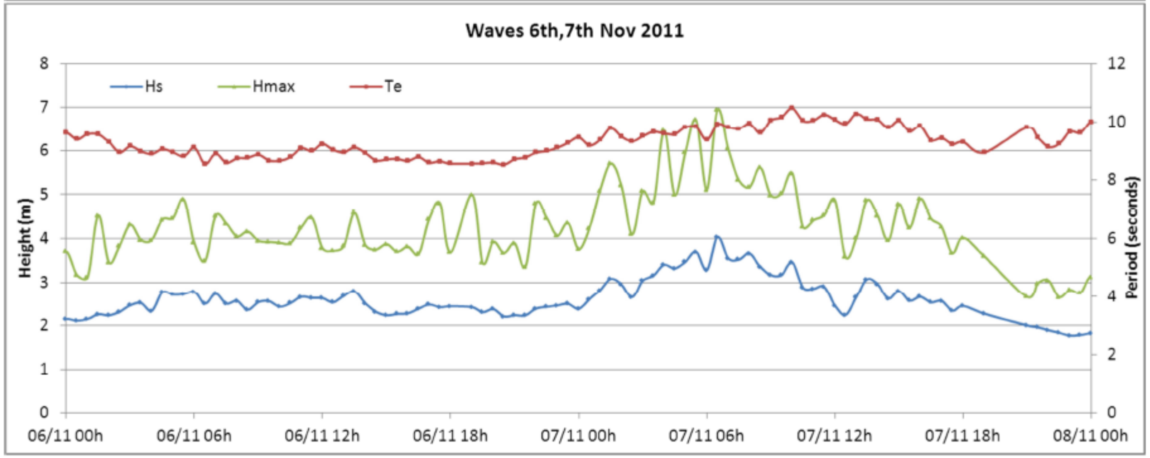


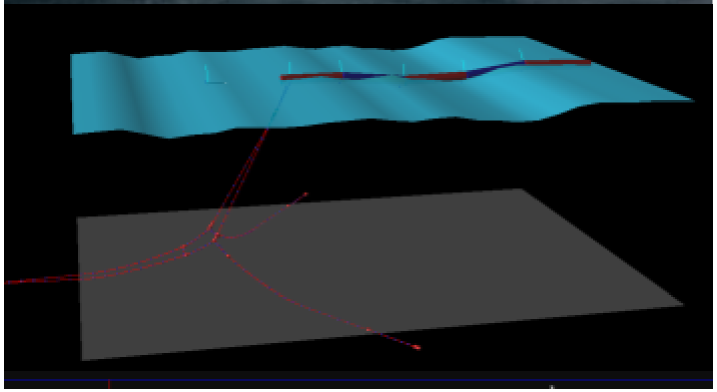
pelamis wave power

Commercial in Confidence

Comparisons with real machine in real seas







- Agreement between simulations and real measurements at sea
- Average over extended periods is within a few per cent
- Demonstrated over most sea occurrences – testing continues.

pelamis wave power

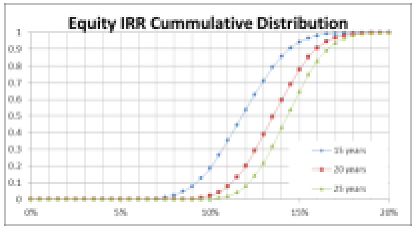
Pelamis – Cost of Energy Drivers

VALIDATED ASSUMPTIONS

Run iterations

Progress	Iterations	Update rate
2000	2000	500

Machine option 4



select above option	Perf (kW ann avg) mean	stdev	Machine installed cost (£m) lower	mode	upper	Rating	CF	notes
1	162	0.082	3.02	3.20	3.42	0.5	32.4%	
2	273	0.082	3.39	3.62	3.89	0.8	34.1%	Concrete
3	202	0.082	3.59	3.82	4.07	0.6	33.7%	
4	345	0.082	4.06	4.32	4.61	1.0	34.5%	Concrete

MONTE CARLO INPUTS

PARAMETER	Generated	Expected	LOWER	MODE	UPPER	MEAN	STDEV
Annual average Shetland (kW)	359	345				345	0.082
Machine installed cost (£m)	4.323	4.330	4.056	4.322	4.611		
Spares (£m)	0.87	0.80				0.8	0.2
Project development (£m)	1.05	1.00	0.9	1	1.1		
Availability	92.9%	93.0%	0.91	0.93	0.95		
Transmission efficiency	97.5%	98.0%	0.97	0.98	0.99		
£m/MW Balance of plant	0.30	0.30	0.25	0.30	0.35		
£/MWh (equivalent 5 x ROCs)	320.4	320.0	300	320	340		
O&M (£k/machine/yr)	50	50	45	50	55		
Grid charges, TNuoS etc £k/MW/yr	131	125	80	100	195		
Other operating costs £k/yr	150	200				200	20
Annual insurance (% capex)	1.3%	1.2%	0.01	0.012	0.014		
Annual lease costs (% sales)	0.33%	0.34%	0.0033	0.0034	0.0035		
Decommissioning (£m/machine)	0.11	0.10	0.05	0.1	0.15		

<u>Validated Inputs</u>:

- Costs, performance, O&M models, balance of plant, facilities, etc

<u>Cost of Energy modelling:</u>

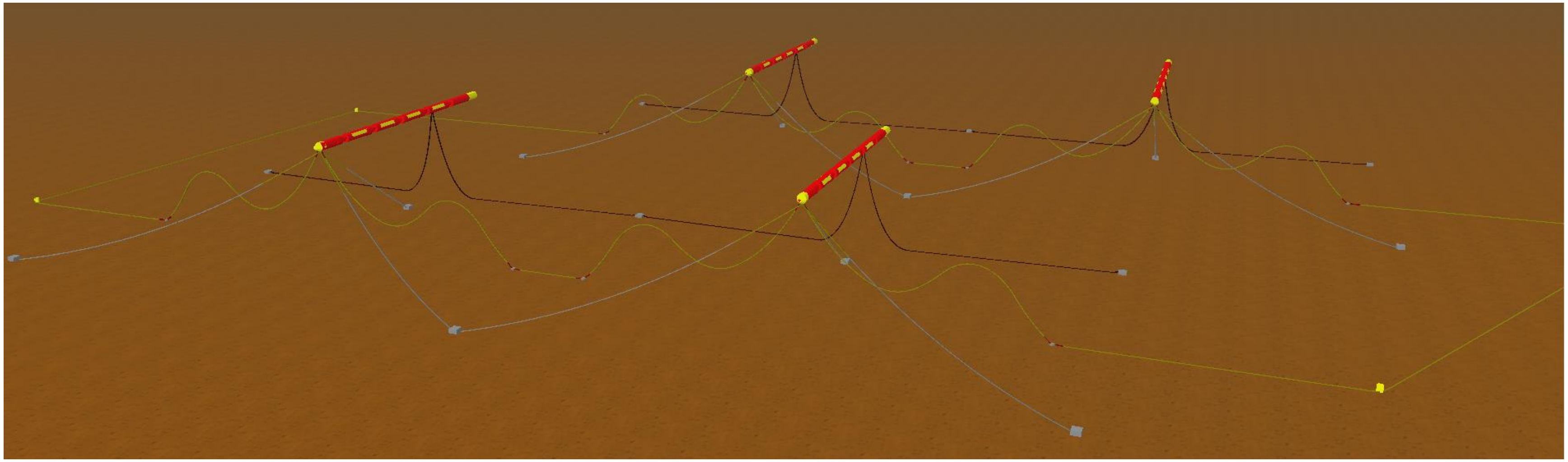
- Full project model
- Quantify uncertainty
- Peer-reviewed

pelamis wave power

Addressing Environmental Risks in Project Development

Stakeholders include bodies such as Investors, Marine Scotland, MCA, NLB, Historic Scotland, with very different interests –

- Project and financial risks - consent
- Safety of other marine users
- Impact on marine mammals
- Impact on fish and on fishing
- Preservation of historic wrecks, etc.



www.pelamiswave.com

Facebook

Martin Shaw, Offshore Systems Director.
m.shaw@pelamiswave.com

Commercial in Confidence