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Wave & Tidal Energy

Research for PE elective – MBA 11J

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This report has been developed as part of the INSEAD elective on private equity and is not intended to provide any investment advice

Our understanding of WHEB's need

The aim of this project is to identify companies or divisions that have developed technology to generate energy from tidal or wave power. These companies should have the potential to grow rapidly over the next 3 to 5 years as a result of private equity funding. The types of private equity deals that can be considered are growth capital and late-stage venture with a deal size up to £10 million. LBO's are beyond the scope of this project. In line with WHEB's profile, the focus should be on Europe

More specifically we are looking for companies with the following characteristics:

- Active in wave or tidal energy value chain, focus on technology
- Active in Europe
- In commercial phase, generating revenues
- Deal size in the range £5-10M

Remark: this report does not attempt to evaluate companies from a technical point of view

Source: Group proposal letter

Management summary

Wave & Tidal are still early stage technologies

- Prototypes have been rolled out, but commercial exploitation limited

Capacity for wave & tidal expected to grow in the near future

- $1.2B in investments forecasted over the next 5 years, implying ~150 MW of installed capacity[1]
- UK most active market currently and expected to have majority of installed capacity[1]

UK seems European center for Wave technology deployment, innovation and financing

- No consensus on technology/design so far, bulk of wave projects are still in testing phase

Tidal attention has been growing the last years, but currently most are still in early stage

- European tidal projects mainly use tidal current technology

Few players in commercial phase at the moment, but funding increased in recent years

- Annual funds raised from ~10M annualy before 2005 to ~80M annualy in last five years raised[2]
- Size of funding rounds seems in line with search criteria

1. Douglas-Westwood report 2010
2. New Energy Finance

Agenda

General Overview

Trends in Wave

Trends in Tidal

Company search

Wave and Tidal are two different ways to extract energy from water movement

Wave energy

"Wave energy occurs in the movements of water near the surface of the sea. Waves are formed by winds blowing over the sea surface, and the water acts as a carrier for the energy. The amount of energy in waves depends on their height and period (the time between successive peaks).

The annual average power per unit length of wave crest (e.g. 40 kW/m) is a first indicator of how energetic a particular site is."

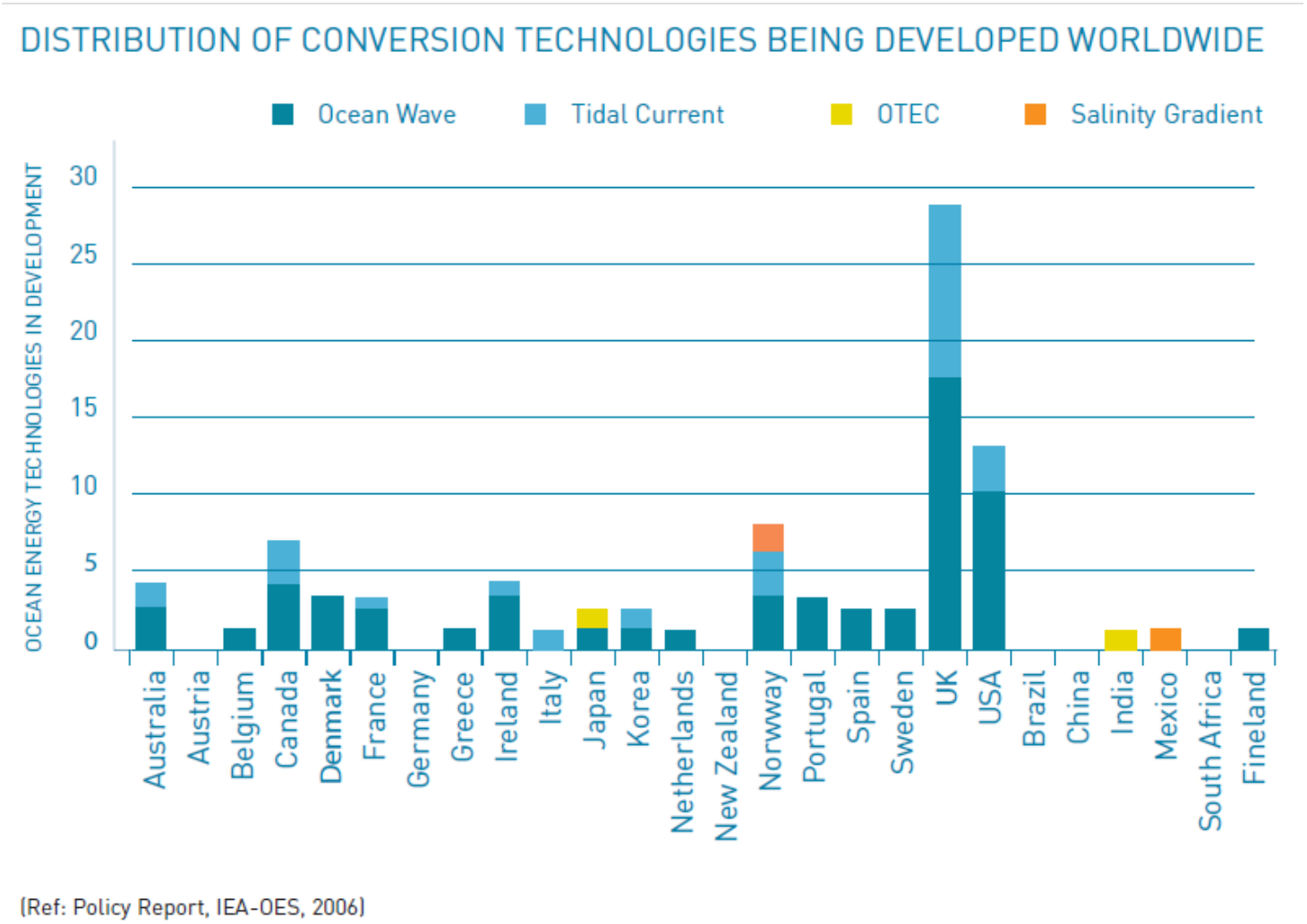
Tidal energy

"Tidal streams are caused by the familiar rise and fall of the tides, which occurs twice a day around the UK coast. As water flows in and out of estuaries, it carries energy. The amount of energy it is possible to extract depends on the speed of the flowing stream and the area intercepted. This is similar to wind power extraction, but because water is much denser than air, an equivalent amount of power can be extracted over smaller areas and at slower velocities.

The mean spring peak velocity is a first indicator of how energetic a tidal stream site is."

Source: IEA, Carbon Trust

Currently the UK and the US are the most active Wave & Tidal conversion technologies



(Ref: Policy Report, IEA-OES, 2006)

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Overall supply chain for successful project management in wave and tidal is similar in services needed

Areas	Research & Development	Feasibility /opportunity	Planning	Design	Manufacturing	Installation	Maintenance & Service	Maintenance & Service
Key services	• Energy conversion • Energy storage/usage • Prototyping • Investment	• Geophysical • Environmental • Competing use • Final feasability	• Project planning • Permits • Insurance • Finance • Legal • Power purchase agreement	• Project design • Offshore design • Mechanical design • Hydrodynamic design • Electrical systems design • Civil onshore design • Control systems	• Moorings • Floating / offshore structure • Energy coupling system • Power generation equipment • Power transition equipment • Common equipment • Control equipment • Energy storage systems • Onshore structures • Resource assessment equipment • Component testing	• Onshore assembly • Cable laying • Transportation • Offshore construction • Civil (onshore)construction • Environmental monitoring	• Integrity mgmt • Performance evaluation • Repair / recovery • Reliability mgmt • Structural monitoring • Environmental monitoring	• Offshore disassembly • Transportation • Recycling / waste disposal • Refurbishment • Environmental compliance

Focus on companies with technology angle in this report

Source: Altprofits, Wave and tidal energy report, Jan 2011

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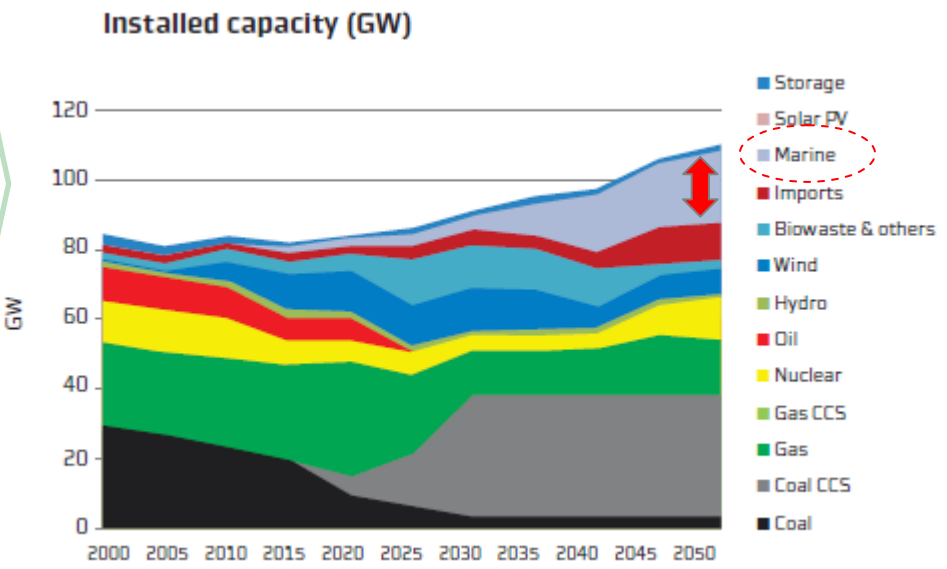
Demand for Wave generation expected to grow

Wave energy is still one of the least mature renewable energy technologies…

- "Ocean energy is the most immature of the renewable power sectors, and asset investment has remained much less important than venture capital support for the dozens of young companies that are developing wave and tidal devices"[1]
- Asset finance in ocean energy rose from virtually nothing in 2008 to $0.2 billion in 2009, although most activity still consists of pilot and demonstration plants[1]
- Major constraints:
  - Requires state subsidies
  - Technology not mature

…but projects could be increasing significantly in the future given adequate political support

Indicated impact ocean energy in a UK aggregated scenario [2]



Sources: (1) Renewables 2010 Global Status Report, Renewable energy policy report for the 21st Century
(2) OCEAN ENERGY: GLOBAL TECHNOLOGY DEVELOPMENT STATUS, IEA March 2009

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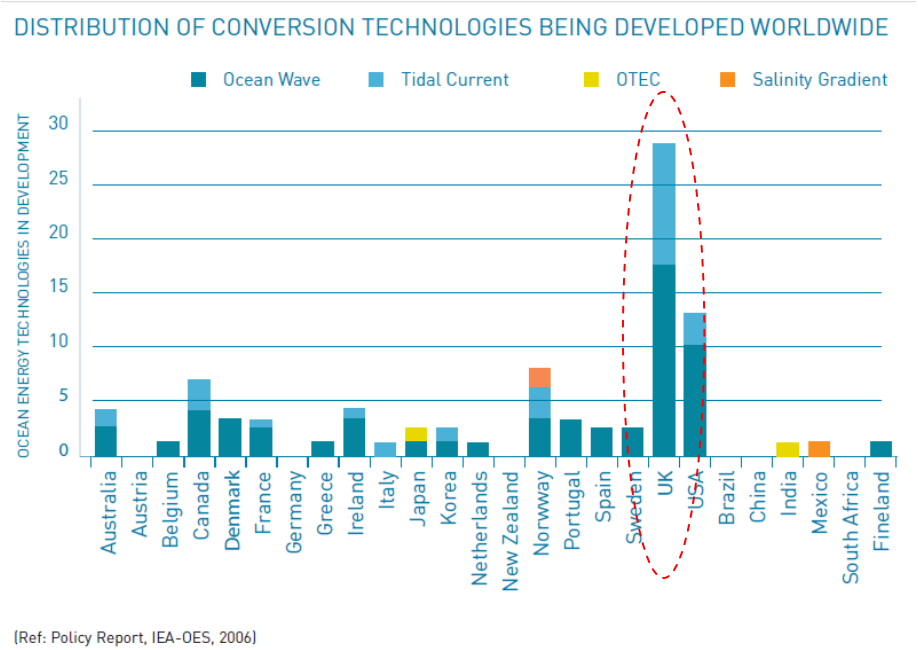
UK likely to stay the European center for Wave technology deployment, innovation and financing

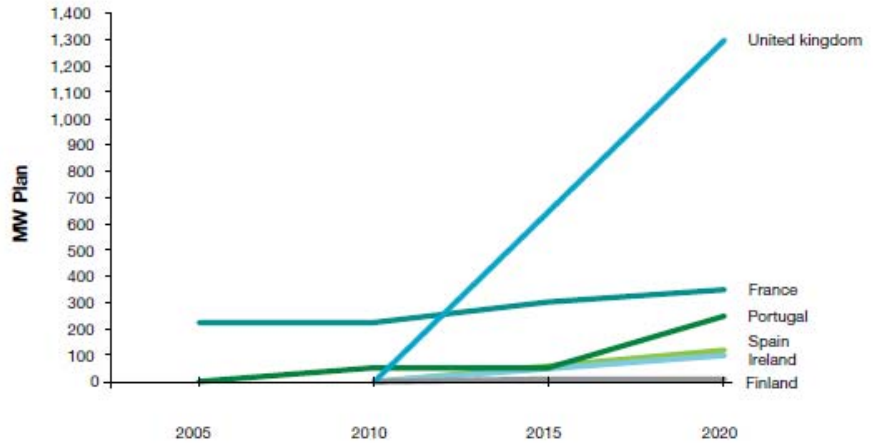
Currently the UK is globally the most active Wave & Tidal market…



(Ref: Policy Report, IEA-OES, 2006)

…and political support should be keeping the UK on top of the pack

Marine Energy Targets for EU Member States 2010 – 2020[1]



Source: (1) Renewable UK - Wave and Tidal Energy in the UK State of the industry report

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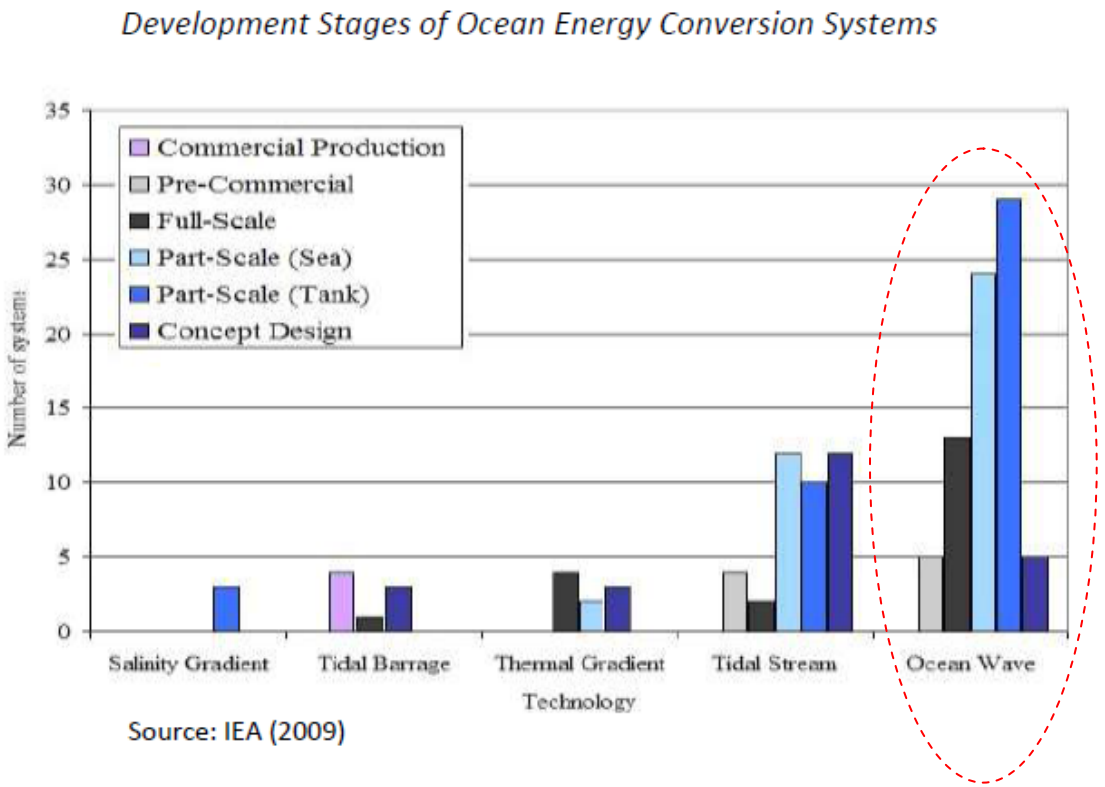
Wave technology shows no design consensus so far…

Absorbers	Attenuator	Overtopping Devices	Oscillating water column (OWC)	Oscillating Wave Surge Converter	Others
A point absorber is a floating structure which absorbs energy in all directions through its movements at/near the water surface. The power take-off system may take a number of forms, depending on the configuration of displacers/reactors. **Main Examples:** **•OPT (PowerBuoy)** **•AWS Ocean Energy** **•SyncWave Energy** **•Fred Olsen**	An attenuator is a floating device which works parallel to the wave direction and effectively rides the waves. Movements along its length can be selectively constrained to produce energy. It has a lower area parallel to the waves in comparison to a terminator, so the device experiences lower forces. **Main Examples:** **•Pelamis** **•Wave Star Energy**	This type of device relies on physical capture of water from waves which is held in a reservoir above sea level, before being returned to the sea through conventional lowhead turbines which generates power. An overtopping device may use collectors to concentrate the wave energy. **Main Examples:** **•Wave Dragon**	An oscillating water column is a partially submerged, hollow structure. It is open to the sea below the water line, enclosing a column of air on top of a column of water. Waves cause the water column to rise and fall, which in turn compresses and decompresses the air column. This trapped air is allowed to flow to and from the atmosphere via a turbine, which usually has the ability to rotate regardless of the direction of the airflow. The rotation of the turbine is used to generate electricity. **Main Examples:** **•Ocean Energy (OE Buoy)** **•Wavegen Voith Hydro** **•OceanLinx (former Energetech)**	This device extracts the energy caused by wave surges and the movement of water particles within them. The arm oscillates as a pendulum mounted on a pivoted joint in response to the movement of water in the waves. **Main Examples** **•AquaMarine Power**	This covers those devices with a unique and very different design to the more wellestablished types of technology or if information on the device's characteristics could not be determined. For example the Wave Rotor, is a form of turbine turned directly by the waves. Flexible structures have also been suggested, whereby a structure that changes shape/volume is part of the power take-off system. **Main Examples** **•Wello Oy**

Source: IEA Oceans, 2009, EMEC, Wave and Tidal Energy in the UK - State of the industry report (www.renewable-uk.com)

…and the bulk of wave projects are still in testing phase



Source: IEA (2009)

Testing considerations

- On-shore devices are more reliable and easier to maintain, but they offer less exposure to the energy source
- Wave energy is less predictable than tidal energy requiring technologies to aggregate and smooth the electricity output
- Hydraulic systems could transmit the energy on-shore instead of generating electricity off-shore
- Limiting the number of moving parts in the sea seems key to reducing maintenance costs
- Must be designed to cope with rough sea conditions

Examples of wave projects currently in testing or pre-commercial phase

Attenuator

Pelamis
Floating, articulated device
Assembling of the first offshore wave farm off Northern Portugal
(Ocean Power Delivery, UK)

Wave Dragon
Slack-moored overtopping
Sea testing in Nissum Bredning, Denmark
(Wave Dragon ApS, Denmark)

Overtopping Devices

Oscillating water column (OWC)

Limpet
Shore-based OWC plant in Islay, Scotland
(Wavegen, UK)

OE Buoy
Floating OWC system
Sea testing in Galway Bay Test Site, Ireland
(Ocean Energy Ltd, Ireland)

Oscillating water column (OWC)

Absorbers[1]

AWS
Submerged device
Sea testing off Northern Portugal
(AWS II BV, Netherlands)

PowerBuoy
Free-floating point absorber
Sea testing in Hawaii
(Ocean Power Technologies, USA)

Absorbers

1: AWS submerged device failed after more than 3 years of preparation, highlighting the risks even for well funded & late stage prototypes.
Source: IEA (2009), Tom Thorpe (Oxford Oceanics)

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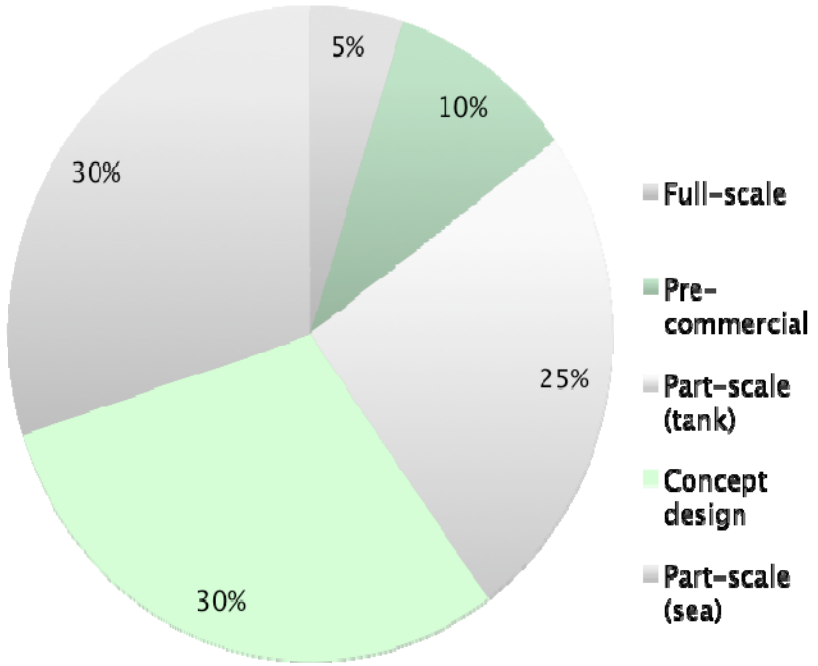
Tidal energy attention has been growing the last years, but currently most are still in early stage

Tidal energy attention has been growing the last years

- At least 25 countries are involved in developing
  - During 2009, South Korea completed a 1 MW tidal-current plant and began construction of a 260 MW tidal plant.
  - Europe added at least 0.4 MW of ocean power capacity., with 58MW being developed in the UK
- Annual capital expenditure $52 million in 2010,set to rise to $500 million by 2015,
- Installations in 2011 are more than double those in 2010
- Total of 150MW of wave and tidal current stream capacity is forecast to be installed between 2011-2015

…but currently most are still in early stage



Source: OCEAN ENERGY: GLOBAL TECHNOLOGY DEVELOPMENT STATUS, IEA March 2009
World Wave and Tidal Market Report 2011-2015 report by Canterbury
Renewables 2010 Global Status Report, Renewable energy policy report for the 21st Century

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Within tidal, current and barrage are the two main approaches

	Tidal Current [1]		Tidal barrage
	Horizontal axis	Vertical axis	
Description	• Directly in stream, energy from flow of water • Turbine with horizontal-axis of rotation blades • Reasonably predictable	• Directly in stream, , energy from flow of water • Vertically mounted blades work well with different flow directions • Reasonably predictable	• Different basin/dam techniques • Water via turbines out barrages generate power • Very predictable
Viability & maturity	• Most common form of tidal current • Early stage	• Early stage	• Proven technology since 1966 • several commercial up to 240MW
Challenges	• Disperse and power proportional to tidal velocity • Difficult to access to maintenance	• Disperse and power proportional to tidal velocity • Difficult to access to maintenance	• Environmental (wide area) • Can't control peak time generation • High investment
Links to other techniques	• Wind energy • Turbine mainly Permanent magnet, some induction and pressurized hydraulics	• Wind energy (insignificant usage) • Turbine mainly Permanent magnet, some induction and pressurized hydraulics	• Other hydro-electrical power techniques • Turbines: mainly bulb and straflo
Indication of cost	• 17 cents/kW for <10MW; 4-9 cents/kW >100MW		• ~20-40 Cents/kW

1 Excludes new (theoretical) technologies (such as pressure tubes , shrouded turbines) and overlap in wave (venturis and oscillating foils)
Source: IEA Oceans 2009
Pike Reserach

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Tidal current seems to most developed technology (based on number of projects and suppliers)...

Tidal Current

Horizontal axis

- SeaGen, Marine Current Technology UK
- Verdant Power, Verdant Power LL US
- Hammerfest – Turbine, Hammerfest Strom A, Norway
- UEK Turbin, UEK Systems US
- Clean Current Tidal Turbine, Clean Current Canada
- TidEL, SMD Hydrovision UK
- Open-Centre Turbine, OpenHydro Group Ltd Ireland
- Tocardo, Teamwork Technology BV Netherlands
- Evopod, Oceanflow Energy, Overberg Ltd UK
- Scotrenewables Tidal Turbine (SRTT) Scotrenewables UK
- Swan Turbine, Swan Turbines UK
- Rotech Tidal Turbin, Lunar Energy UK
- Semi-Submersible Turbine, TidalStream UK
- Marenergie, Pole Mer Bretagne France
- Tidal Stream Generator, Tidal Hydraulic Generators Ltd UK
- TidalStar, Bourne Energy US
- DeltaStream, Marine Energy Generation Lt UK
- Hydrokinetic Generator , Kinetic Energy Systems US
- Statkraft Tidal Turbine, Statkraft, Norway
- Submerged Tidal Turbine , Tidal Generation Limited UK

Vertical axis

- Gorlov Turbine, GCK Technology Inc US
- Kobold Turbine ,
- Ponte Di Archimede International S.p.A Italy
- Wanxiang Vertical Turbine ,Harbin Engineering University, China
- Davis Hydro Turbine, Blue Energy Canada
- EnCurrent Turbine,
- New Energy Corporation Inc Canada
- Ducted Vertical Turbin, Coastal Hydropower Corporatio Canada
- EXIM Tidal Turbin, SEA Power Sweden
- Neptune Proteus Tidal Power Pontoon, Neptune Renewable Energy UK
- Impulsa Turbine,, UNAM Engineering Insitute Mexico
- Atlantisstrom, Atlantisstrom Germay
- WWTurbine, Water Wall Turbine, Canada
- Cycloidal Turbine , QinetiQ Lt UK
- Vertical Axis Ring Cam Turbine / Polo device,,Edinburgh University UK

Tidal barrage

- La Rance Barrage, EDF France
- Annapolis Barrage , Nova Scotia Power Canada
- Sihwa Tidal Barrage , Ministry of Maritime Affairs and Fisheries Korea
- China Barrages (Jiangxia, others) , China
- Kislaya Guba , Russia
- Offshore Tidal Lagoons , Tidal Electrics UK
- Tidal Delay , CleanTechCom, Woodshed Technologies Australia
- Two-Basin Barrage , UNAM Engineering Institute Mexico

Source: IEA Oceans, 2009

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…however some early research is done in other techniques

- **Stringray, The Engineering Business Ltd UK (hydrofoil)**
- **Pulse Generator , Pulse Generation Ltd UK (hydrofoil)**
- **Harmonica, Tidal Sails AS, Norway (hydrofoil)**
- **bioStream,BioPower Systems Australia (hydrofoil)**
- **HydroVenturi, HydroVenturi Ltd, UK (??)**
- **Superconducting Magentic Energy Storage (SMES), Neptune System NL (??)**
- **Gentec Venturi ,Greenheat Systems Limited, UK (??)**

Agenda

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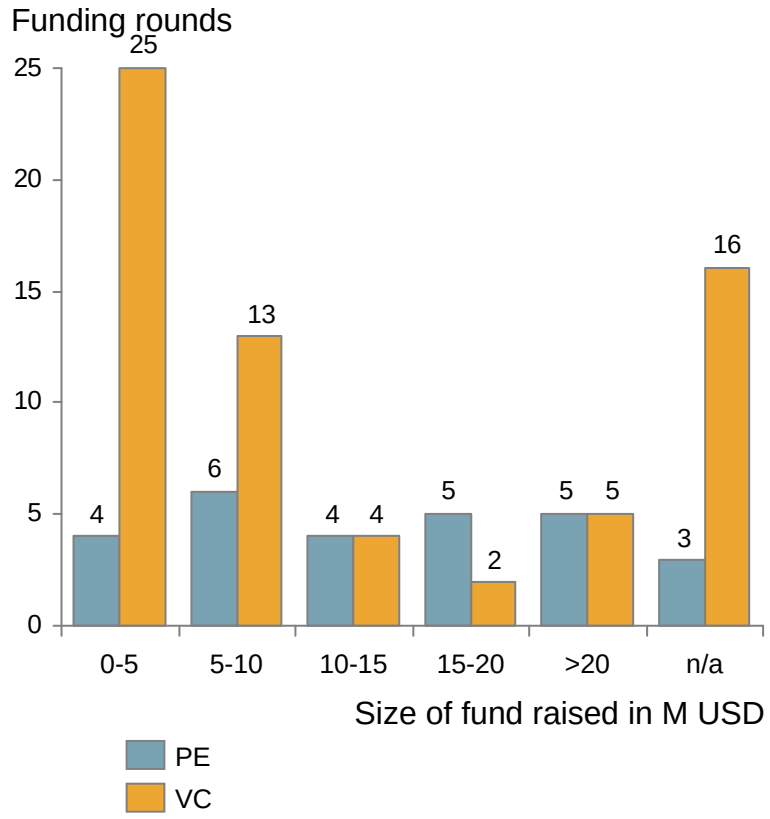
Trends in Tidal

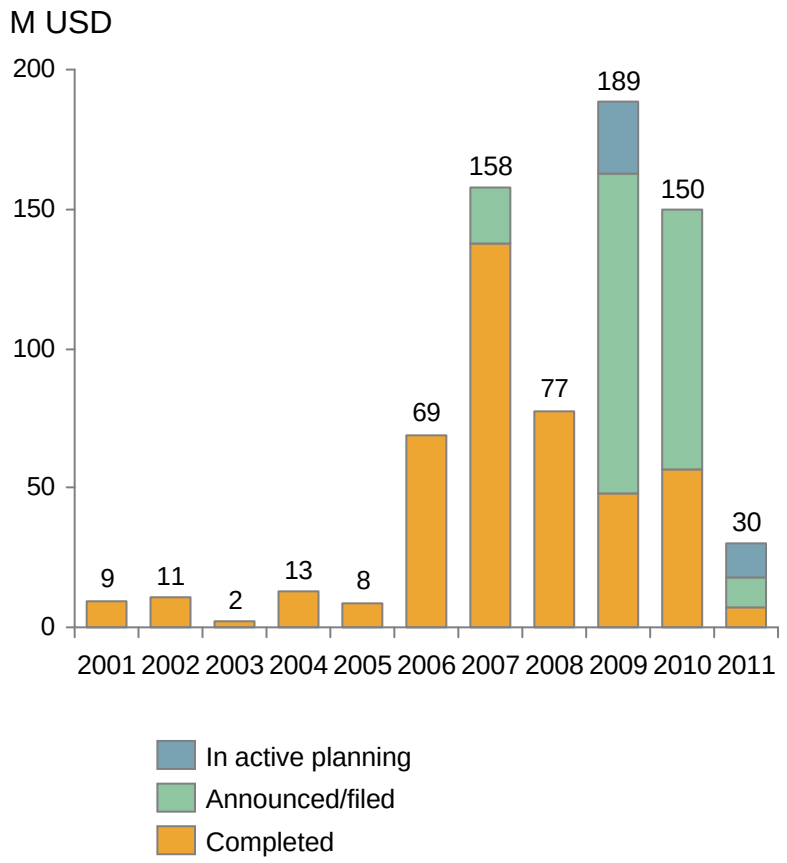
Company search

Average size of funding rounds seems to fit WHEB criteria and fundraising has increased in recent years

Majority of funding rounds under $20M



Amount raised increased in recent years



Source: BNEF download, April 25th 2011

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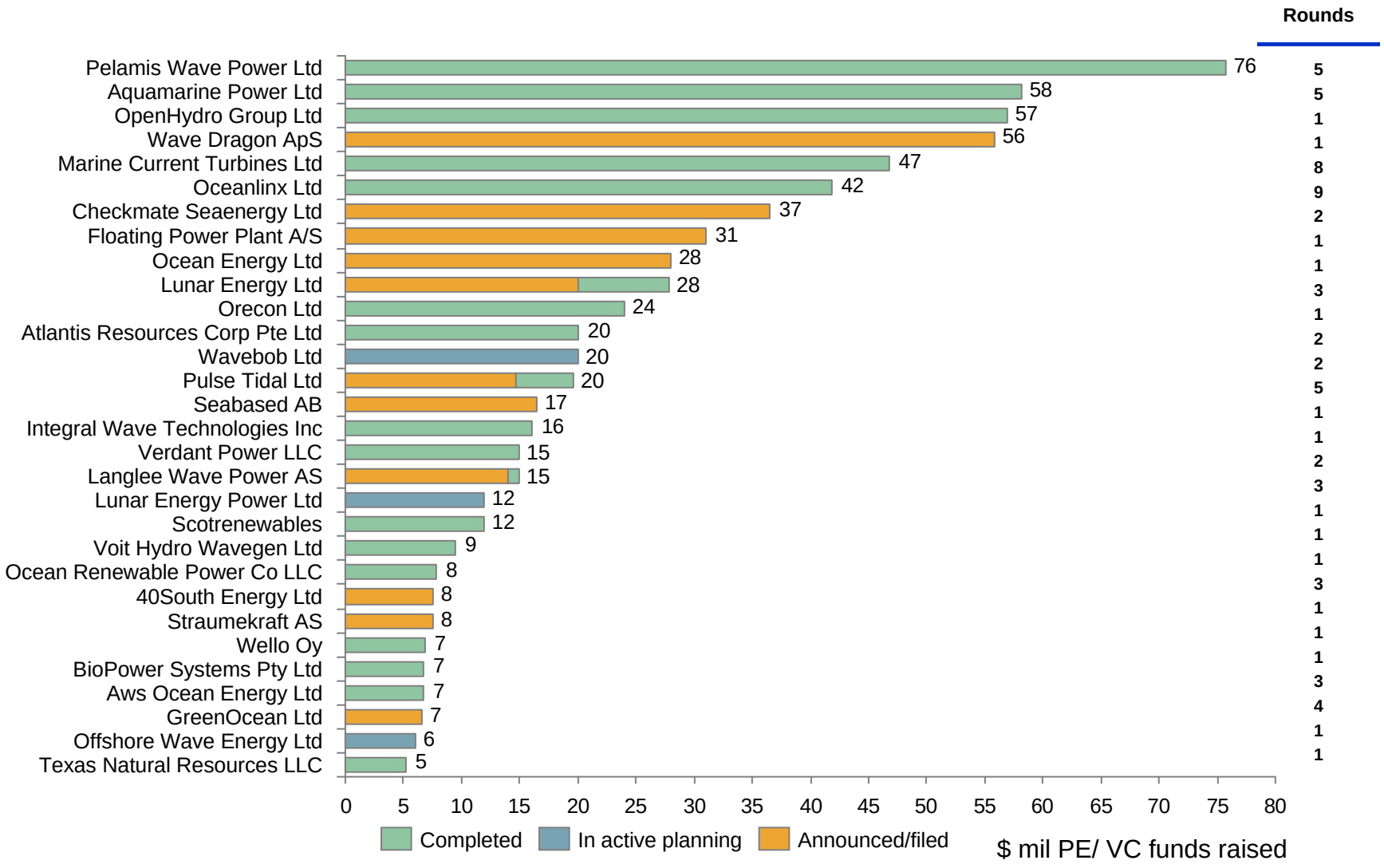
Backup: Overview of cumulative funds raised by wave & tidal technology companies



Source: BNEF download, April 25th 2011

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Shortlist for both Wave and Tidal based on bottom-up search process

Search criteria

Potential target firms must fit certain search criteria

- Active in the field of wave and tidal power generation with a close tie to technology
- Already been able to generate some revenues
- Suitable for late stage investment (no venture of growth equity)
- Size of investment between $5M and ~$15M
  - open for clubdeals or late entry
- Geographically located in UK or Europe

But as most firms are privately held, financial information is scarce

- Makes search for firms that already generate revenues hard

Bottom-up search process

Alternatively, we look for firms whose technology is planned to be used in projects

- Rationale: if firms start delivering their products, revenues will follow automatically

Five step process to filter attractive companies

- Create comprehensive list of all announced wave/ tidal projects (based on Bloomberg New Energy Finance database)
- Extract projects with equal or more than 5MW planned capacity
- Determine technology provider for each of these projects (based on public information)
- Create shortlist and profiles of most attractive technology providers (based on CapitalIQ)
- Review with expert (Tom Thorpe (Oxford Oceanics))

Search process resulted in shortlist for both Wave and Tidal technology companies that have a project pipeline

- Some shortlisted companies have announced new financing rounds

CapitalIQ profiles are attached to provided more detailed information

Remark: this report does not attempt to evaluate companies from a technical point of view

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Shortlist of potentially attractive companies in Wave powered generation based on pipeline of projects

Not according to criteria

Company name	Technology	HQ Country	Potential project pipeline[1]		Ownership	Status[2]
			Total MW	# projects		
Aquamarine	Oyster wave	Scotland	400	2	Private	4*
Pelamis	Pelamis P2	Scotland	219	6	Private	5*
Wavebob	Wavebob	Ireland	150	1	Private	3
SDE	SDE Buoys	Israel	65	3	Private	3
Wave Dragon	Wave Dragon	Denmark	57	2	Private	3
OPT	PowerBuoy	US/ UK	64	4	Public listed	4
Oceanlinx	<unknown>	Australia	27	1	Private	4
Langlee	<unknown>	Norway	24	1	Private	2
CETO	CETO	Australia	20	2	Carnegie owned	3-4
Seabased	WEC	Sweden	10	1	Private	4
Biopower	bioWave	Australia	10	1	Private	4
Hidroflot	Hidroflot	Spain	6	1	Private	4

***Energias de Portugal**; **Poseidon's Organ**; **Ocean Energy Buoy (OWC)**; **Wave Star Energy and Wavegen (Voith-Siemens)** should also be considered in a shortlist with a **status 4** – expert opinion (Tom Thorpe (Oxford Oceanics))*

1: Potential project Pipeline represents the total possible inventory pipeline, both projects under "contract" and "memorandum of understanding"
2: Status is a reflection of the state of technological development : 1 - Theoretical; 2 - wave tank tests on model; 3 - small scale tests in sea; 4 - demonstration prototype; 5 - commercial deployment; * project underway with major utility (Source: Tom Thorpe (Oxford Oceanics))

Source: BNEF project database, Tom Thorpe (Oxford Oceanics)

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Shortlist of potentially attractive companies in Tidal powered generation based on pipeline of projects

Not according to criteria

Company name	Technology	HQ Country	Potential project pipeline[1]		Ownership	Status[2]
			Total MW	# projects		
Bluenergy	Tidal stream	Canada	2,400	2	Private	3
Rotech	Tidal stream	UK	300	1	Private	2
Openhydro	Tidal stream	UK	200	1	Private	3-4*
MCT	Tidal stream	UK	501	3	Private	5*
Hammerfest Strøm	Tidal stream	UK	190	1	Private	4-5*
Atlantis	Tidal stream	Singapore	125	4	Private	2-3*
Cambarine	Tidal lagoon	UK	60	1	Private	1[3]
Tocardo	Tidal stream	NL	10	1	Private	4

Alstom Beluga *(status 2);* ***Voith Hydro (****status 3);* ***Tidal Generation Ltd*** *(status 4) and* ***Statkraft*** *(status 4), should also be considered in a shortlist - expert opinion (Tom Thorpe (Oxford Oceanics))*

1: Potential project Pipeline represents the total possible inventory pipeline, both projects under “contract” and “memorandum of understanding”
2: Status is a reflection of the state of technological development : 1 - Theoretical; 2 - wave tank tests on model; 3 - small scale tests in sea; 4 - demonstration prototype; 5 - commercial deployment; * project underway with major utility (Source: Tom Thorpe (Oxford Oceanics))
3. Due to the nature of the technology, this company will not follow all five stages, but moves directly from 1 to 5 if it goes ahead

Source: BNEF project database, Tom Thorpe (Oxford Oceanics)

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