MARINE RENEWABLE ENERGY
Offshore Wind, Tidal Stream, Wave

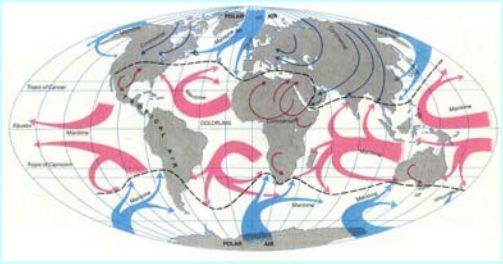
-Professor Trevor Whittaker FREng.

01 – 12 - 2006

Contents

- The technologies
  - Offshore Wind
  - Tidal Currents
  - Wave Power
- Common technical challenges
- Concluding remarks

Weather systems



Fetch, Duration, Wind strength

Technology at Existing Wind Farms Sites in Europe

Middelgrunden, Denmark

Utgrunden, Sweden

Technology at Existing Wind Farms Sites in Europe

Blyth, UK

Nordex 2.5MW

Offshore Wind Farm Construction

Drilling operations

Tower & turbine installation

Visual impact

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Wind power development UK

- 134 operational wind farms –
  - 1640 MW onshore , 304 MW offshore
- Offshore (up to 3.6MW/ unit)
  - 765MW approved
  - 4,283MW submitted
- If all were installed (load factor 0.33)
  - 1.77GW or 4.5% of ave. UK demand produced
  - 2.5MW/km^2 = 700km^2 of sea surface
    (assumes 3.6MW machines at 0.33 load factor, 100m dia., 2 units / sq. km.)
  - > 10 x this technically possible

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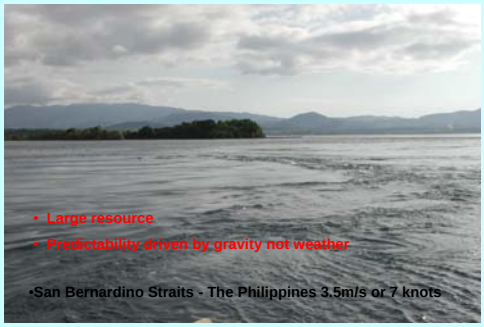
Tidal Current



- Large resource
- Predictability driven by gravity not weather

•San Bernardino Straits - The Philippines 3.5m/s or 7 knots

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Side courtesy MCT Ltd

Potential Tidal Current Energy Sites

requirements: mean spring peak = 2 to 3m/s (4 to 6kt)
water depth 20 to 40m at low tide
however slower continuous currents can be used

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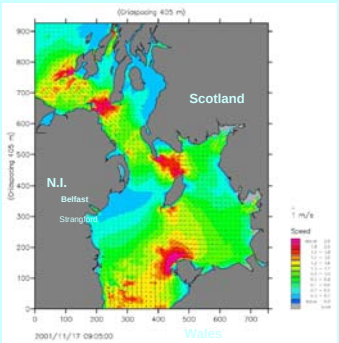
Side courtesy MCT Ltd

Potential Tidal Current Energy Sites (Irish Sea)

This is a computer generated model of the entire Irish Sea tidal flow regime at Spring Tide, 3hrs after HW Belfast

However only areas shown in magenta have enough energy to be useful

image courtesy Kirk McClure Morton



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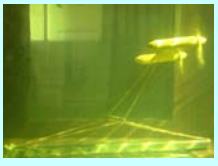
Soil Machine Dynamics (SMD) 10kW test model



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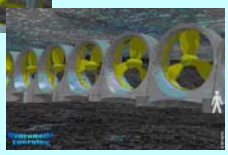
From SMD website

Hydrohelix Energies and Lunar Energy

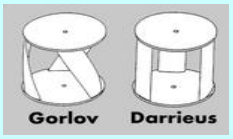


Horizontal axis turbines with rim generators

Tidal fence

From Hydrohelix Energies website

Vertical Axis Turbines

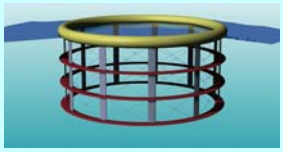


Cross flow turbines
helical & straight blade

'Polo' Device

Variable pitch Darrieus rotor

Professor S Salter
Edinburgh University



Blue Energy Canada Inc. – Prototype Tests

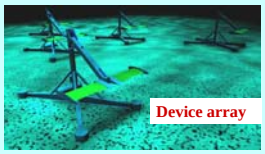
Davis hydro turbine test model

100kW duct mounted unit

From Blue Energy website

VEGA 1 – 4kW unit tested Gulf stream 1984

Engineering Business Ltd. 'Stingray'



Device array

Model prototype launch Yell Sound 2002

From EB website

Seaflow Project – Lynmouth, Devon

Raised for maintenance

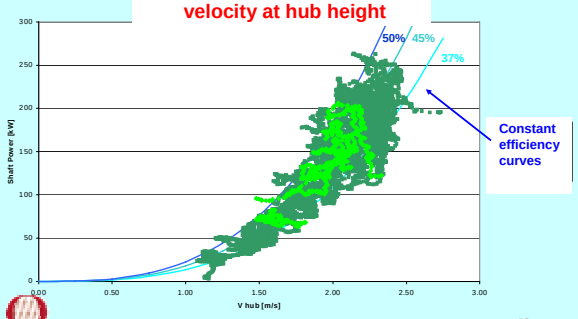
- Seaflow installed
- 30 May 2003
- rotor dia. 11m
- rated power 300kW
- pile dia. 2.1m

Operational mode

Side courtesy MCT Ltd

Seaflow measured rotor performance

Turbine shaft power v current velocity at hub height



Side courtesy MCT Ltd

SeaGen 1.2MW Commercial Prototype

- to be tested in Strangford Narrows, N Ireland
- already under construction
- due for installation Dec 2006 or Jan 2007
- will be used as testbed for SeaGen technology
- will have continuous environmental monitoring

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Side courtesy MCT Ltd

Seagen: power trains

- 16m diameter rotors with full span pitch control
- steel and composite cross-arm
- twin 600kVA induction generators

input shaft power: 700 kW
input speed: 12 rpm nominal
design torque: 400 kNm
speed ratio: 1:83

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Side courtesy MCT Ltd

Gearbox, hub and generator under test

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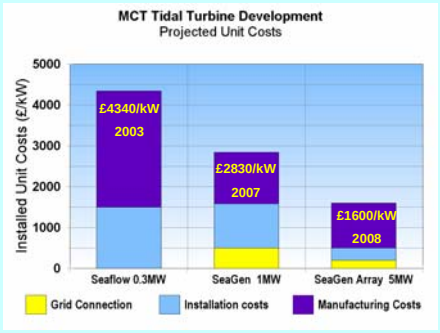
Side courtesy MCT Ltd

Key Project Costs – short term



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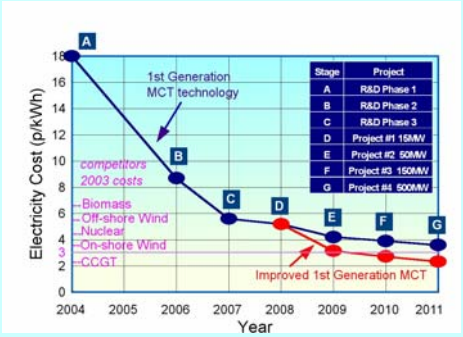
Driving Down Costs



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100 MW Stations

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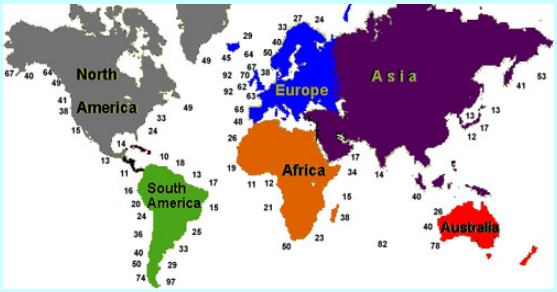
Examples of UK Tidal Current Energy Sites

Location	Depth (m)	V spring (m/s)	V neap (m/s)	2nd/1st tide ratio	Energy (GWh/y
Hoy, Pentland Firth	76	4.38	1.8	0.85	1377
S Ronaldsay, Pentland firth	58	4.89	2.05	0.77	1518
Stroma, Pentland Firth	71	5.15	2.20	0.88	2774
S Ronaldsay, Pentland Skerries	63	4.38	1.79	0.75	1147
Pentland Skerries	59	6.18	2.64	0.67	3901
Duncansby Head	65	5.15	2.20	0.88	2031
Rathlin Island	80	2.57	1.44	1.00	866
Irish Sea Rathlin Sound	40	2.93	1.46	0.84	235
Mull of Galloway	80	2.57	1.44	0.82	806
Casquets	115	2.57	1.39	0.71	1651
Big Russel	48	2.57	1.39	0.88	294
Race of Alderney	39	4.38	2.41	0.96	1365
Total					**17965**

- *From Black & Veatch 2004 prepared for Carbon Trust (Marine Energy Challenge)*
- *Assumes only 20% of resource can be extracted – could be up to 50%*
- *Overall system efficiency - 31%*

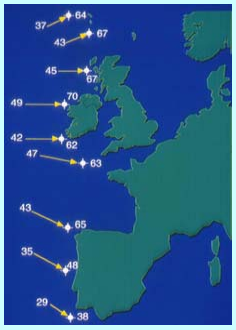
Total output ~ 18TWh/yr

Global wave resource



Average annual wave resource kW/m deep water

European wave resource



European Resource

400 TWh

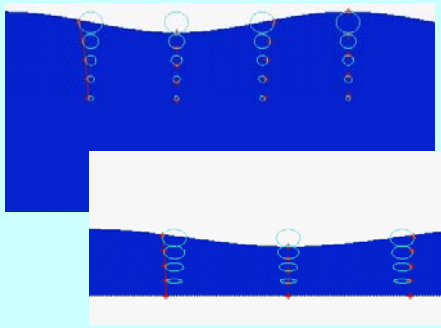
17% of EU demand

UK Resource

61 87TWh

20% of demand

Characteristics of waves



Deep water Offshore

Shallow water Near Shore

Design challenges in wave energy

- **Convert KE & PE in waves to useable form**
  - Elliptic fluid particle motion – large cyclic forces
  - Irregular frequency, amplitude, direction
  - Extreme loads can be > 100 x working average
- **Wave power converters must**
  - Survive extremes
  - Produce a predictable defined output
  - Compete with other forms of generators
  - Have a substantial positive energy balance

Configuration options & design choices

Frame of reference
- moving structure - relative to sea bed
- fixed structures - moving water
- relative motion of components

Power take off PTO
- hydraulic
- pneumatic
- mechanical
- electrical

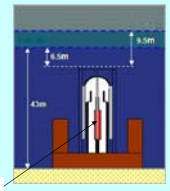
Device types: Terminators | Point absorbers | Attenuators

Location: Offshore | Near shore | Shoreline

Archimedes Wave Swing

moving structure relative to sea bed

- Sea bed mounted
- Array of point absorbers
- PTO - electrical
- Offshore 50m +



Linear generator

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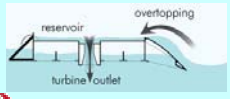
From AWS website

Wave Dragon

Large floating structure moving water

- Reaction & focusing due to physical size
- PTO Low head hydro
- Energy storage
- Offshore 50m +



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From WD website

Pelamis - raft, array, attenuator

- Relative motion between floats
- Attenuator line array
- High pressure hydraulics
- Active stiffness control

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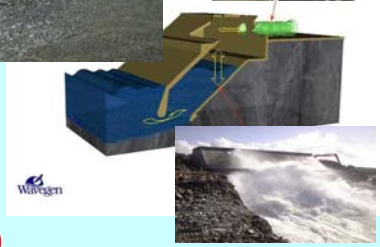
From OPD website

LIMPET OWC



- Fixed structure
- Terminator
- Pneumatic
- Shoreline

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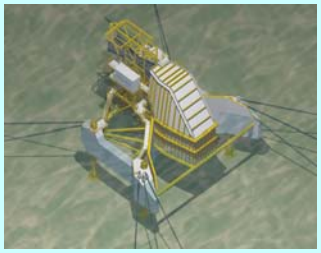
Energetech OWC

fixed structure moving water



- Taut moored
- Array of point absorbers
- PTO - pneumatic
- Near shore 10m+ depth

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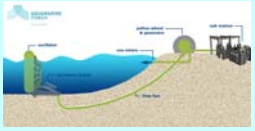
Courtesy Energetech

Oyster™ (moving structure relative to sea bed)

- Sea bed mounted
- Array of point absorbers
- PTO - Hydraulic
- Near shore 10 – 15m



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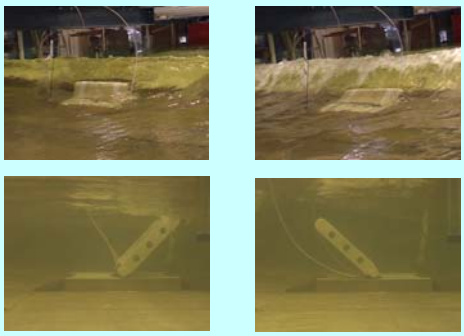
Courtesy Aquamarine Power Ltd.

Oyster™ Survival in plunging breakers

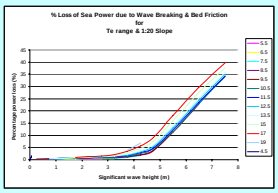


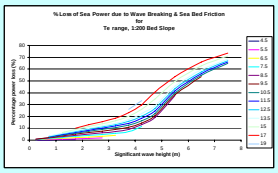
Wave climate EU Atlantic Coast

Hs(m)\Te(s)	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-16	>16	>18	
<.05		1.1	1.3	1.0	0.3	0.1								4
0.5-1.0	2.2	13.5	32.8	34.9	20.8	9.4	5.6	1.2	0.2	0.2				121
1.0-1.5	0.6	17.2	43.1	55.4	38.0	29.7	20.5	8.6	2.7	1.1	0.2			217
1.5-2.0	0.1	5.5	32.1	49.2	40.0	36.6	25.0	13.4	5.5	2.4	1.0	0.1		211
2.0-2.5		0.5	13.2	27.4	31.8	28.0	24.6	18.0	7.7	3.5	1.9	0.2		157
2.5-3.0			2.7	13.2	15.5	20.3	20.2	15.9	10.0	3.8	1.9	0.1		104
3.0-3.5			0.3	4.6	7.5	12.8	13.4	13.1	9.2	4.6	1.7	0.3		67
3.5-4.0				1.1	3.7	7.1	8.4	8.2	5.9	3.5	2.1	0.2	0.2	40
4-4.5				0.2	1.4	4.2	5.8	5.3	3.6	2.6	1.6	0.4	0.1	25
4.5-5.0					0.3	1.8	3.2	3.7	2.7	2.7	1.8	0.2		16
5.0-6.0					0.2	1.5	2.5	3.7	4.2	5.0	6.1	0.5		23
6.0-7.0						0.1	1.2	2.3	2.1	1.1	4.5	0.7		11
7.0-8.0							0.2	0.6	0.4	0.4	0.7	0.2		2
>8.0														0
	3	38	126	187	160	152	131	94	54	31	24	3	0	1000

Max occurance | 0-5kW/m | 5-20kW/m | 20-50kW/m | 50-100 | 100-200 | 200-500

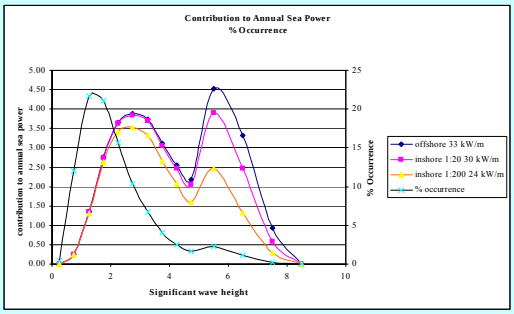
Loss of Sea Power 50m to 10m





- Other factors
- Wave refraction
- current

Offshore – Near Shore Comparison



Oyster power matrix

Oyster power matrix assuming same Hs as deep water, wave saturated above Hs = 4.0m

Significant wave height (m) \ Energy period (secs)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
0.5	idle	idle	idle	idle	idle	idle	1	3	3
1.0	20	30	38	42	44	44	45	47	45
1.5	80	85	92	97	102	103	104	100	104
2.0	140	147	152	158	155	155	160	161	156
2.5	192	197	208	202	203	209	211	201	204
3.0	241	237	237	241	243	230	236	231	235
3.5	-	271	272	269	268	267	270	260	260
4.0	-	291	290	290	280	287	276	278	277
4.5	-	291	290	290	280	287	276	278	277
5.0	-	-	290	290	280	287	276	278	277
5.5	-	-	290	290	280	287	276	278	277
6.0	-	-	290	290	280	287	276	278	277

Pelamis power matrix

Pelamis power matrix taken from OPD website

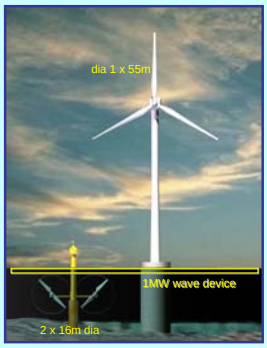
Significant wave height (m) \ Energy period (secs)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	29	37	38	35	29	23	idle	idle
1.5	32	65	83	86	78	65	53	42	33
2.0	57	115	148	152	138	116	93	74	59
2.5	89	180	231	238	216	181	146	116	92
3.0	129	260	332	332	292	240	210	167	132
3.5	-	354	438	424	377	326	260	215	180
4.0	-	462	540	530	475	384	339	267	213
4.5	-	544	642	628	562	473	382	338	266
5.0	-	-	726	707	670	557	472	369	328
5.5	-	-	750	750	737	658	530	446	355
6.0	-	-	750	750	750	711	619	512	415

UK wave energy resource

- Estimates of wave energy generation (Carbon Trust 'Future Marine Energy' 2006)
  - Offshore - 50 TWh/yr (5.7GW)
  - Nearshore – 7.8 TWh/yr (0.89GW)
  - Shoreline – 0.2 TWh/yr (0.023GW)
  - Total –
    - 58TWh/yr (6.6GW)
    - 16.6% of ave. UK demand
    - about 550km of wave front

Technology comparison

A tidal current turbine gains Over 6x as much energy per m^2 of rotor as a wind turbine



Size Comparison 1MW wind turbine compared with 1MW tidal turbine and 1MW wave device.

Technical challenges for all marine renewables

- Cost and weather dependency of marine operations
- Due to infancy of industry;
  - lack of specialised marine vessels
  - engineering challenge of economic sea bed attachment
  - energy harvesting from many small units which are either fixed or floating
  - Maintenance and access
- Accurate full life energy accounting and sustainability

Conclusions

- Offshore wind
  - Established technology *(further developments possible)*
- If all proposed schemes were installed
  - 1.77GW or 4.5% of ave. UK demand produced
  - 2.5MW/km^2 = 700km^2 of sea surface *(assumes 3.6MW machines at 0.33 load factor, 100m dia., 2 units / sq. km.)*
  - > 10 x this technically possible
- Limitations
  - Grid acceptance
  - Public acceptance - visual intrusion etc.
  - Cost 5 – 6p/kWhr

Conclusions

- Tidal stream
  - technology still at very early stage of development
- If 20% of resource extracted, 31% plant efficiency
  - 18 TWh/yr, 2Gw , 5% of UK demand
  - Single line, 11.3MW/km = 180km
  - Double line, 50MW/km^2 = 40km^2
  - Multiple double lines spaced at 1km, 23MW/km^2, 87km^2
- Limitations
  - Performance in exposed wave locations?
  - Floating deep water systems yet to be developed
  - 1st 1.2MW shallow water system built but not demonstrated

Conclusions

- Wave power
  - Technology at very early stage of development
- Power delivery
  - 6 – 12MW/km in average seas 20 – 40kw/m
  - 25 – 30% of incident average power delivered
  - 550km for 6,600MW, 58TWh, 16% UK demand
  - Multiple rows to increase % sea power delivered & reduce coastline length
  - Projected costs similar to offshore wind & tidal current
- Limitations
  - Current cost with very few sea hours demonstrated