Pacific Economic Cooperation Council

Hawaii, USA, March 26-28, 2012

Mechanical energy
wind, waves, current

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French Research Institute for Exploration of the Sea

IFREMER

France

Mechanical Marine Renewable Energy

From resource to energy conversion

Monitoring (sensors)

Device + Conversion process

MRE Converter
Transfer functions
and control

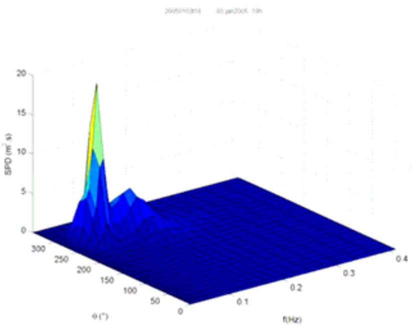
Electricity

Grid connection

Other form of energy: Hydraulic,…

Ground based potential energy

Environment hindcast



www.pelamiswave.com

Significant wave height ($H_{1/3}$, m) \ Power period (T_{pow}, s)	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

Pelamis power ouput
(from Murray 2004)

Mechanical Marine Renewable Energy

Resource and conversion principles

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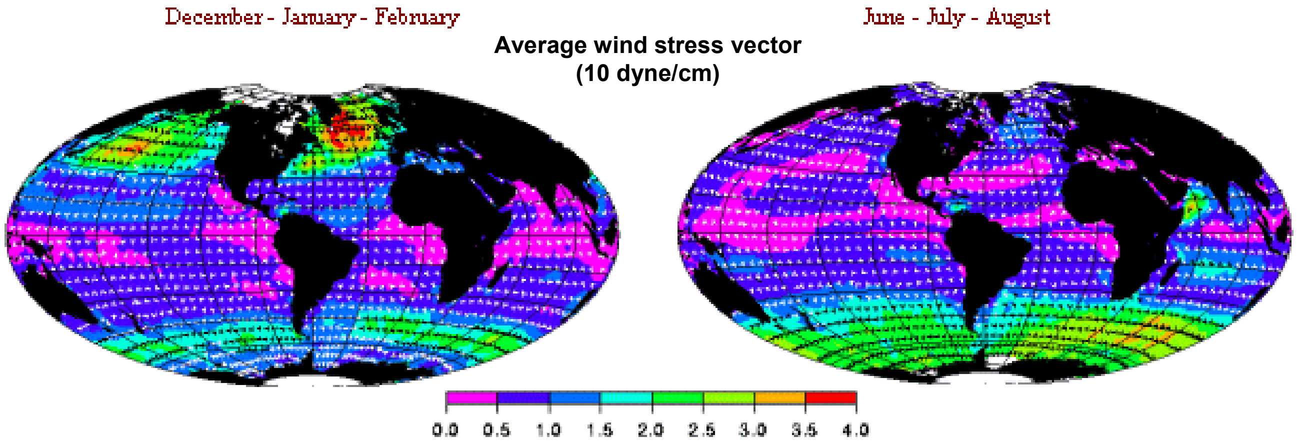
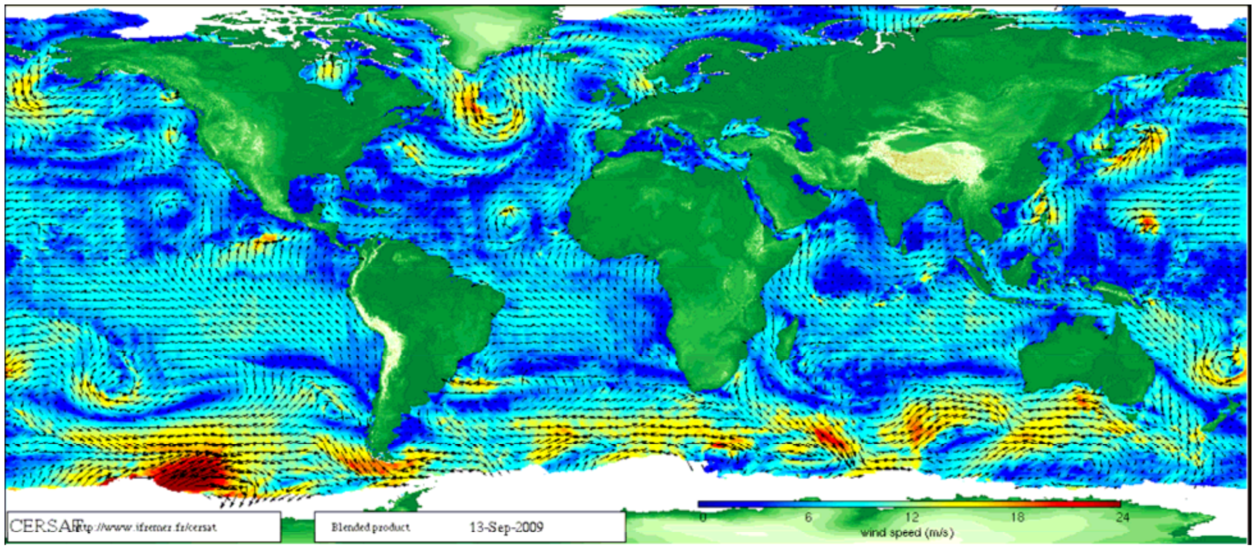
Wind energy

Wind energy is an intermittent resource.
Short term meteorological prediction are improving.
Yearly tendencies are available from large scale observations.



Ifremer-CERSAT



Wind energy

Conversion principles of wind energy are the most mature, based on the experience from terrestrial wind energy.

Differences from terrestrial wind energy :

- sea wind is stronger, more regular and less turbulent compared to ground wind

- the marine environment is more aggressive

- wind turbines and floating support interact :
  - damping effect of the rotor
  - gyroscopic effects of the rotor
  - dynamic stress in the floater, the mast and the turbine

Wind energy

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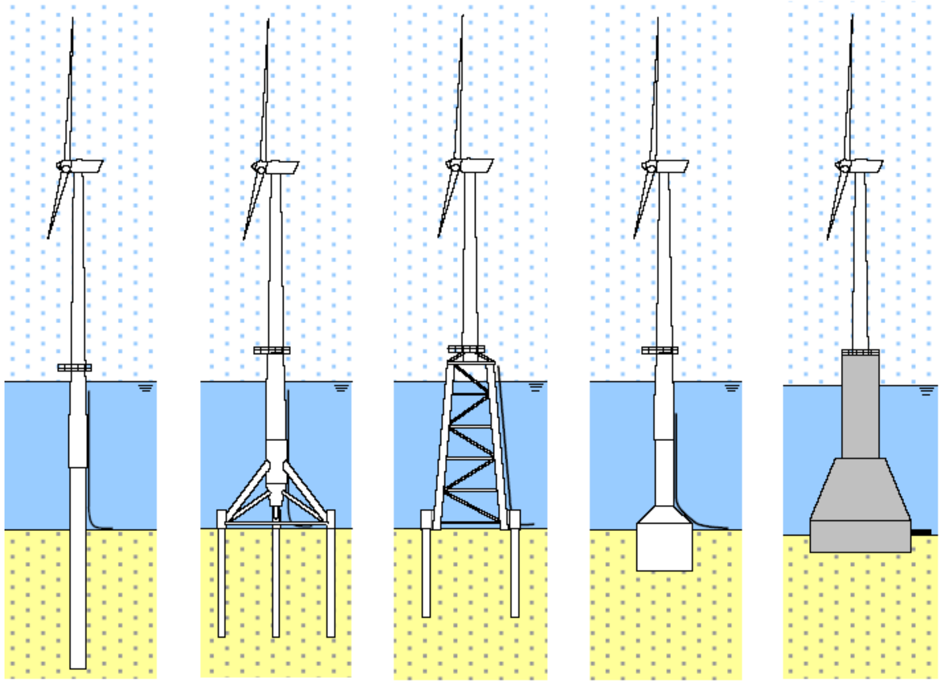
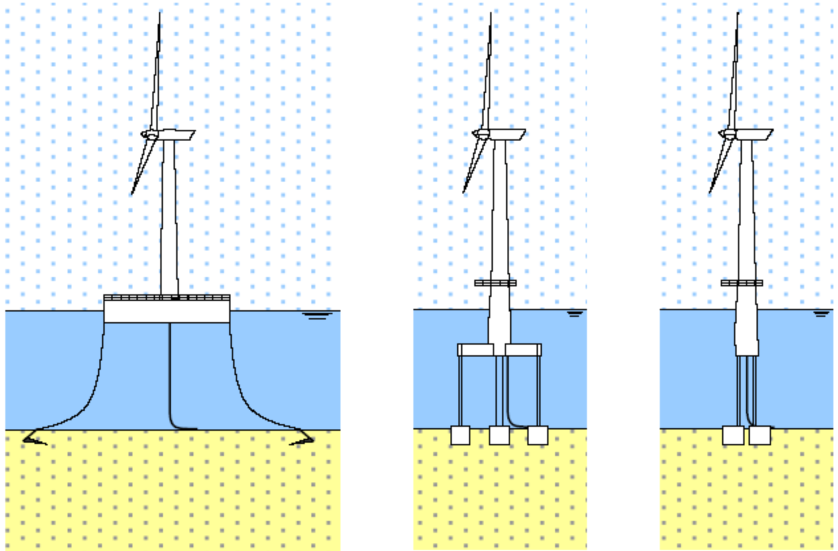


Supports technology derived from the oil and gas industry

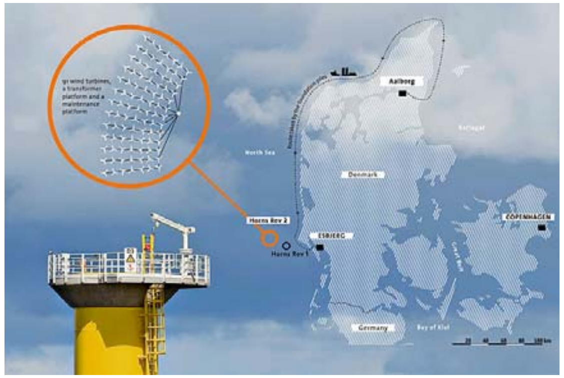
shallow to medium water depth < 50 m

medium to deep water depth

Examples of fixed structures :
mono-pile, tripod, jacket, suction base, gravity base



Examples of floating structures :
semi-submersible
tension leg platform
spar buoy



Horns Rev wind farm, Denmark

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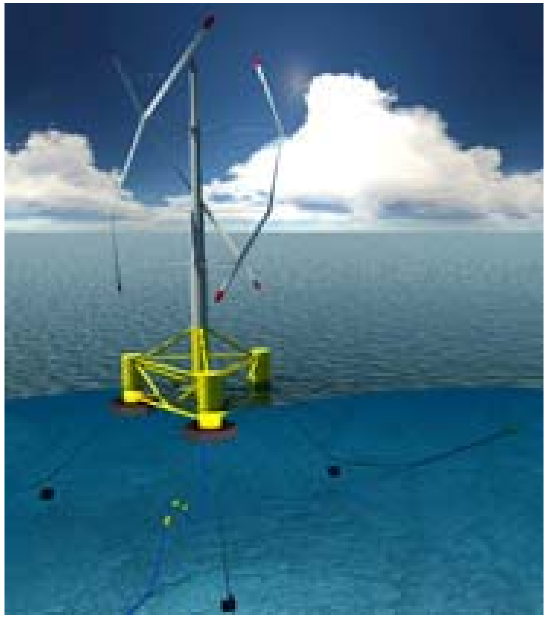
Wind energy

HyWind (Statoil, Norvège)
www.statoil.com 2.3 MW



Nenuphar (France)
www.nenuphar-wind.com

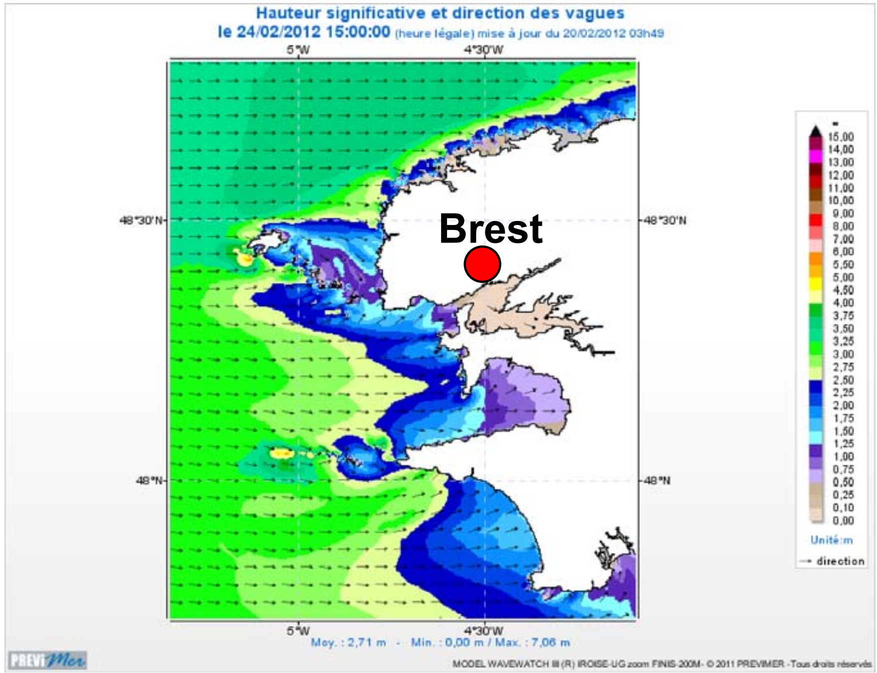
WINFLO (France)
nassetwind.com

Windfloat (USA)
www.principlepowerinc.com/products/windfloat.html

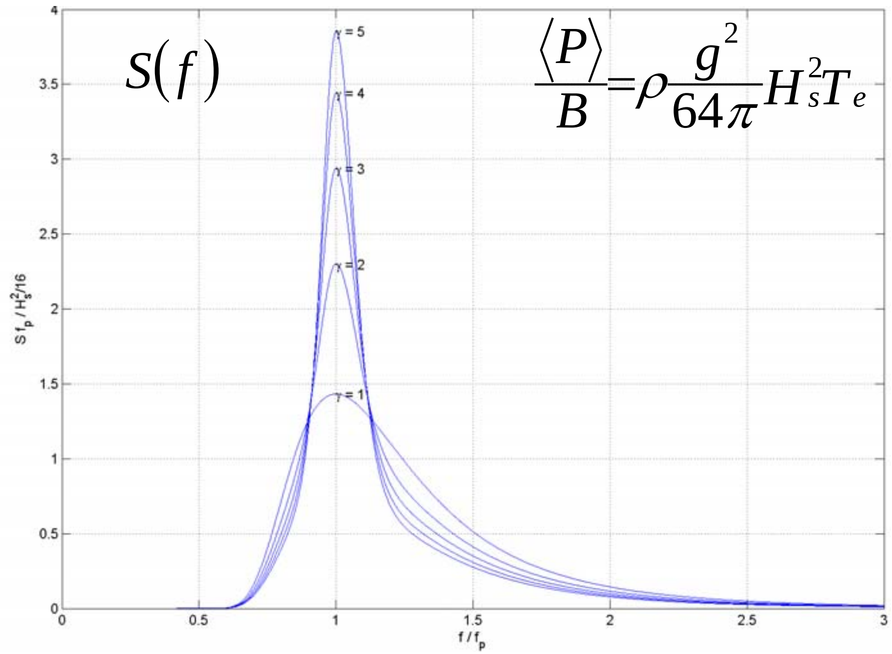
Wave energy

Wind energy is an intermittent resource, related to the far wind generation (swell) and close wind generation (wind seas), characterised by statistics and probability of occurrence of waves spectra, and recorded in waves atlas.

Example of numerical prediction :
Mer d'Iroise, France
www.previmer.org/previsions/vagues



Example of an analytical form of wave spectra :
JONSWAP (*JOint North Sea WAve Project)*



Wave energy

Sea states statistics

Example of sea states statistics based on measurement
Réunion island, France
Relation : Significant wave height – Energy period

RÉPUBLIQUE FRANÇAISE
Ministère de l'Écologie, de l'Énergie, du Développement durable et de l'Aménagement du territoire

CANDHIS
Centre d'Archivage National de Données de Houle In-Situ

Campagne : 97405 - Saint Pierre
Coordonnées : 021°21,170'S - 055°28,660'E
Profondeur : 27.00 mètres

Corrélogramme - Hm0/Te - GLOBAL
(Hauteur significative spectrales des vagues / Priode moyenne nergtique)

hm0 (m)	te (Secondes)																				
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
1	1			1	6	56	220	652	1202	1236	912	382	63	12	2						4745
2						12	447	1989	3659	4270	3700	2933	1724	694	163	24	11				19626
3							6	84	447	1001	1041	772	622	490	235	82	25	7	2		4814
4								6	7	132	185	156	155	139	89	41	4	1	1	1	917
5										1	34	70	74	46	39	12	10	3	1		290
6													6	2	2	5	3	3	1		22
7																3	1	1	2		7
8																	2	1			3
9												1									1
10													1		1	1	2	2	2	1	10
Total	1			1	6	68	673	2731	5315	6640	5872	4314	2645	1383	531	168	58	18	9	2	

Les valeurs du tableau sont exprimées en nombre d'éléments - Les case vides correspondent à des valeurs nulles.

Code des couleurs		
>= 10 ‰	>= 30 ‰	>= 50 ‰

candhis.cetmef.developpement-durable.gouv.fr

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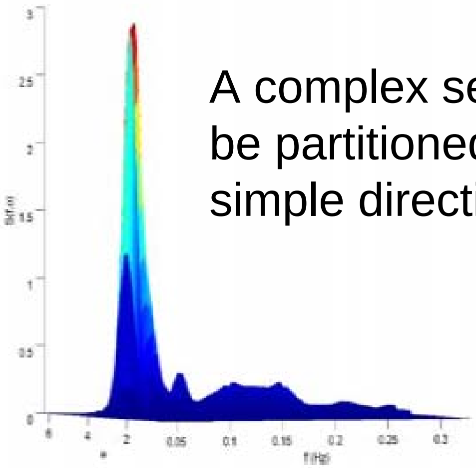
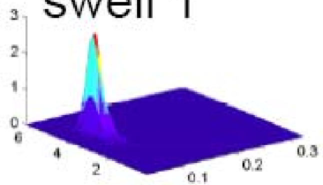
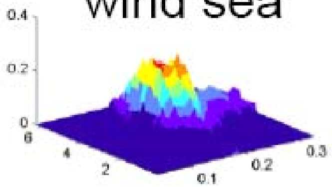
Wave energy

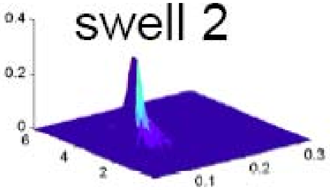
Sea state partitioning



A complex sea state can be partitioned in several simple directional spectra

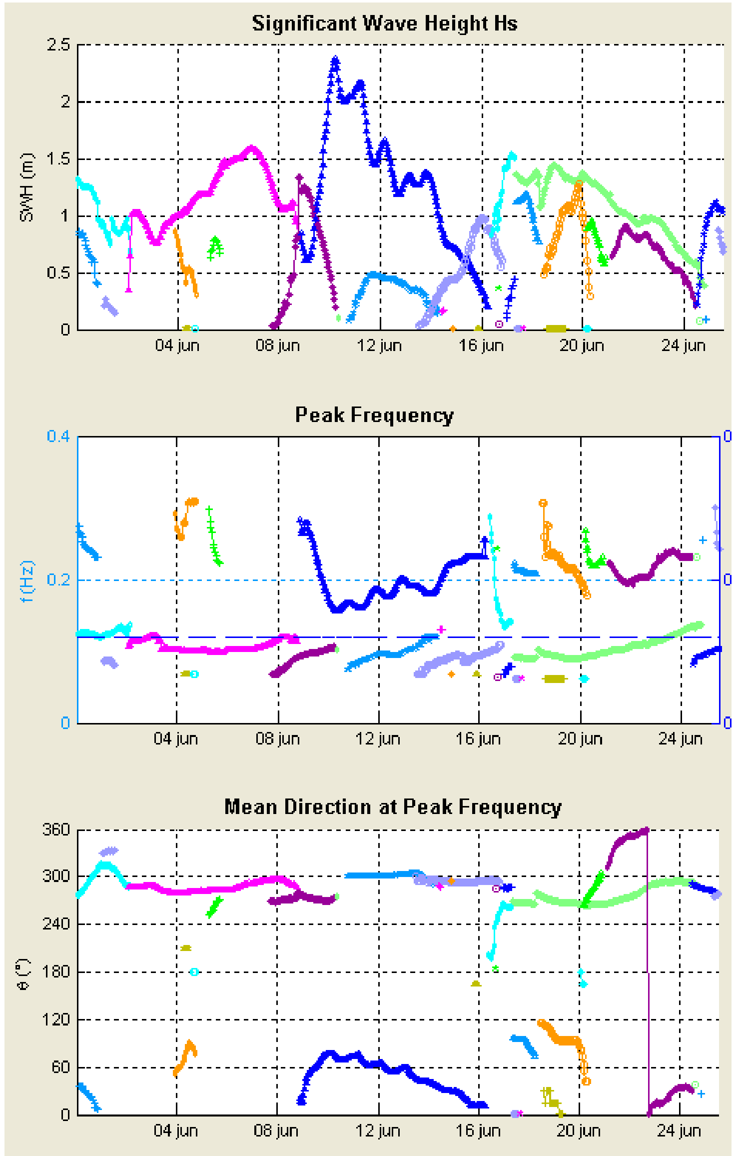






Analysis of sea states parameters give information on the origin of the waves

Sea state tracking



Wave energy

Wave energy conversion principles are the most various and gave rise to many concepts.

The wave energy converters are designed to operate around their natural periods et to stand stresses induced by the most energetic marine environments.

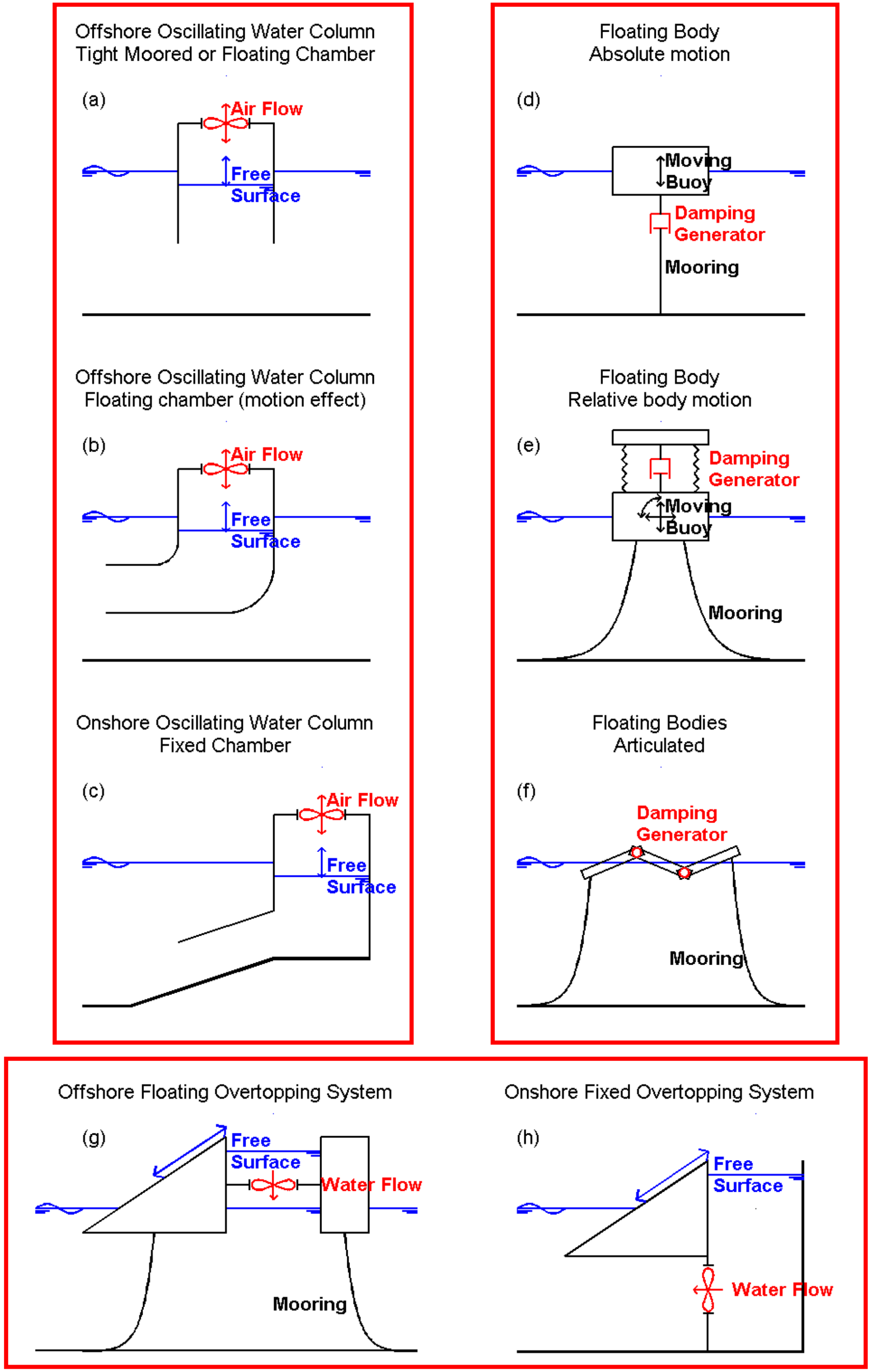
These targets are against the common objectives and operating situation of the ocean vehicles (ships, oil and gas platforms) for which minimum stresses and responses are sought.

Beside the action of waves, actions of current and wind must be taken into account in the design of wave energy converters in terms of energy production and structural strain.

Wave energy

The basic principles
of wave energy capture are :

- oscillating water columns
- moving bodies
- overtopping systems
- other (membranes,…)

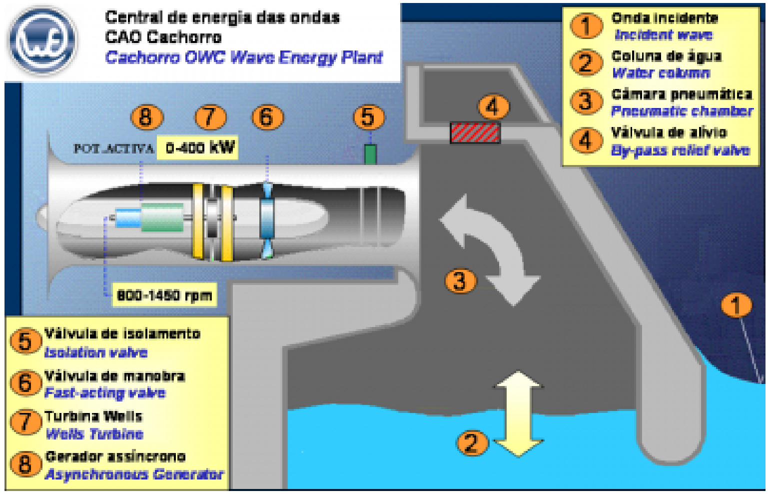


Wave energy

Basic principles of wave energy

- oscillating water columns

Oscillating Water Column in Pico (Açores)
www.pico-owc.net

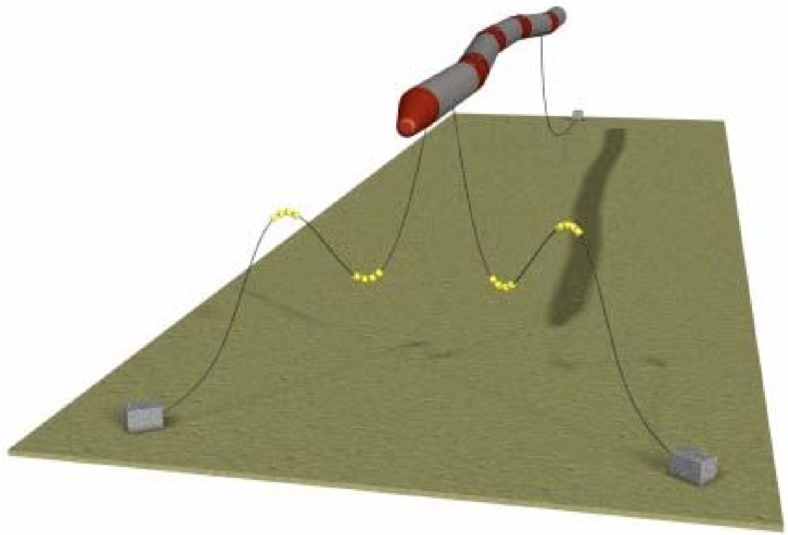


Wave energy

Basic principles of wave energy

- moving bodies

Articulated device : Pelamis
www.pelamiswave.com

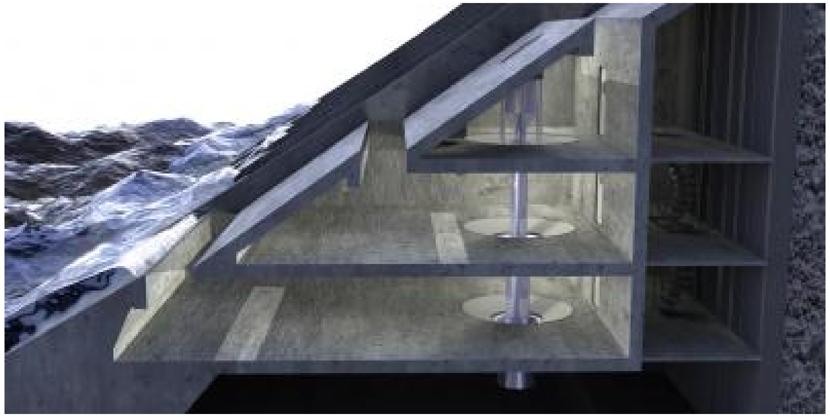


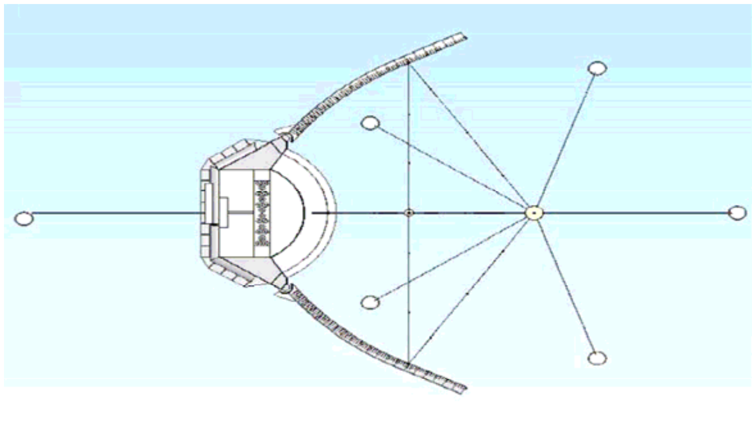
Wave energy

Basic principles of wave energy

- overtopping devices

Floating device : Wave Dragon
www.wavedragon.net





Fixed device : Seawave Slot Cone Generator **www.waveenergy.no**

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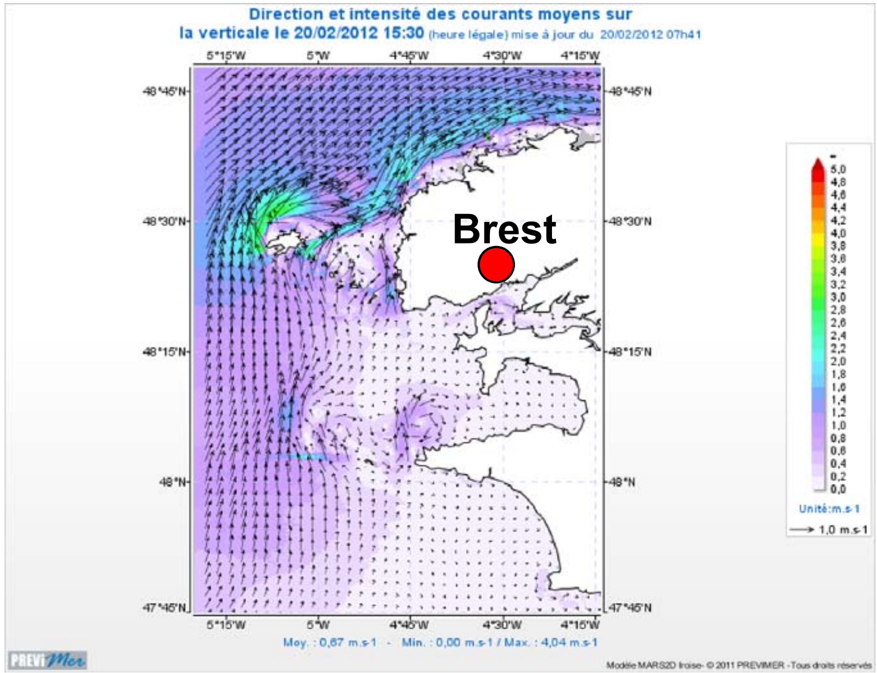
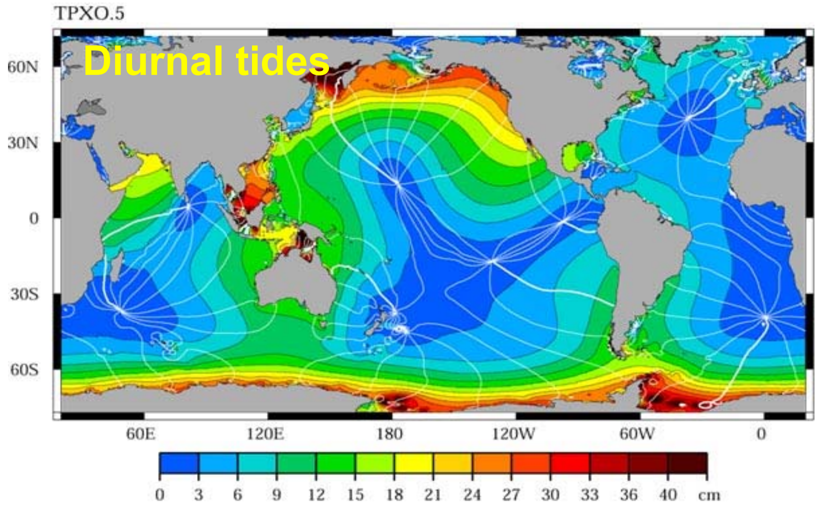
Tidal and current energy

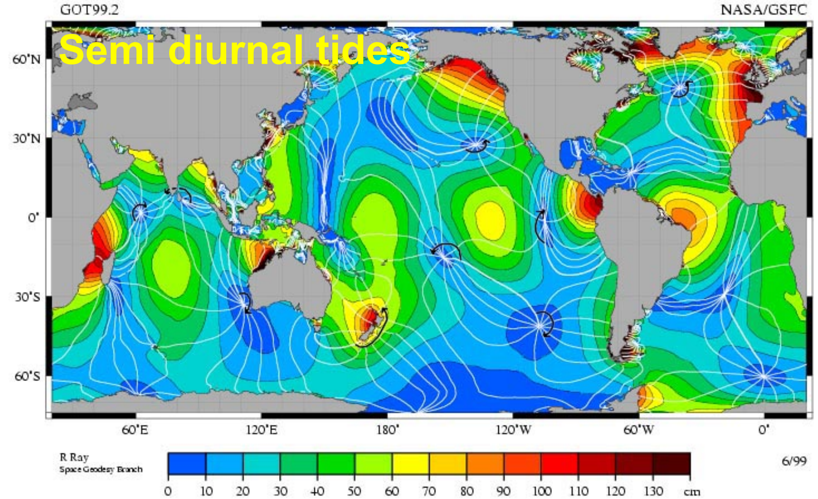
The resource is predictable.
The tidal height and current speed can be computed at a given place and at a given time.

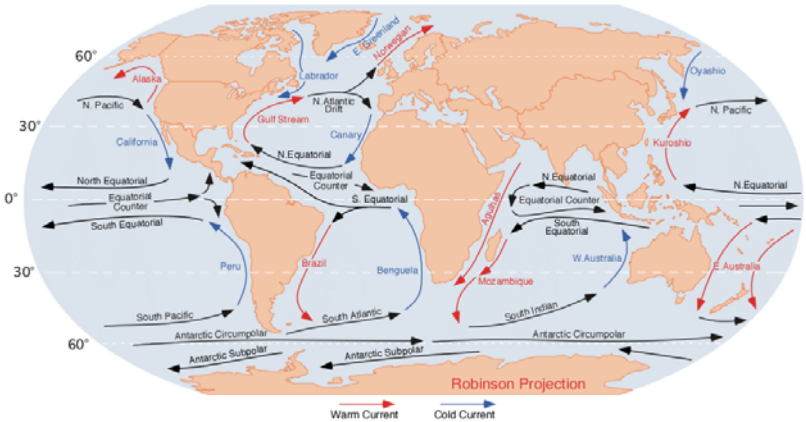
Example of numerical prediction :
Mer d'Iroise, France
www.previmer.org/previsions/courants



Coastal currents



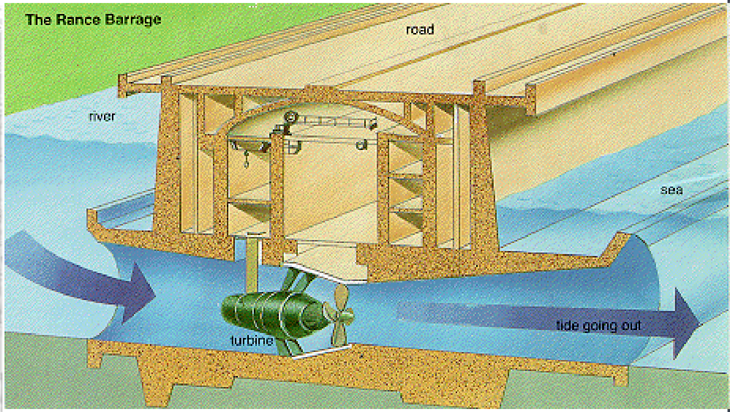


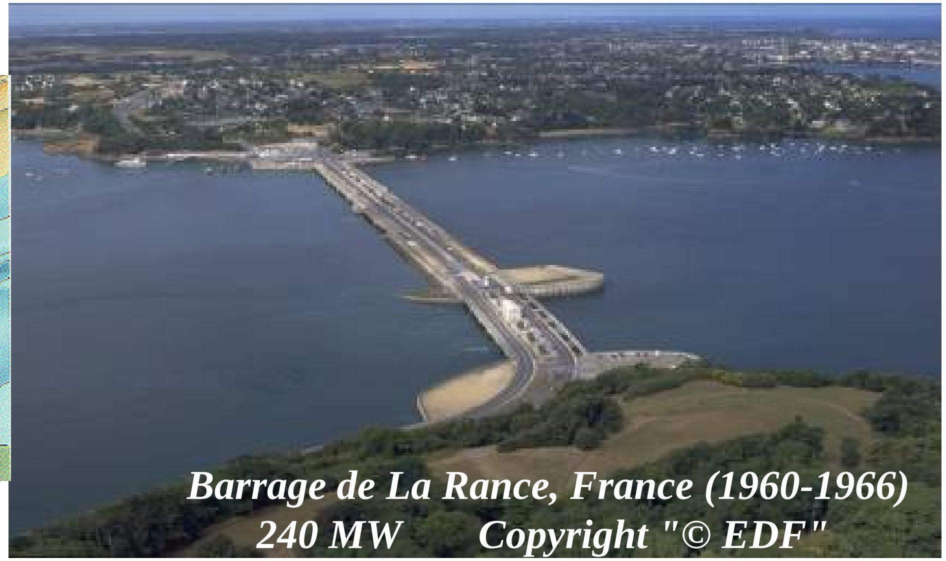


Ocean currents

Tidal and current energy

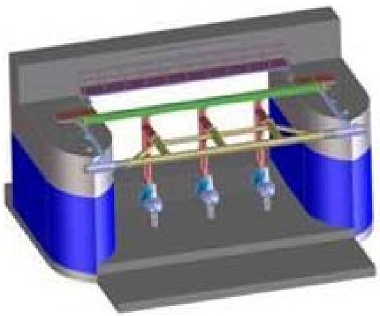
Use of artificial reservoirs





Barrage de La Rance, France (1960-1966)
240 MW Copyright "© EDF"

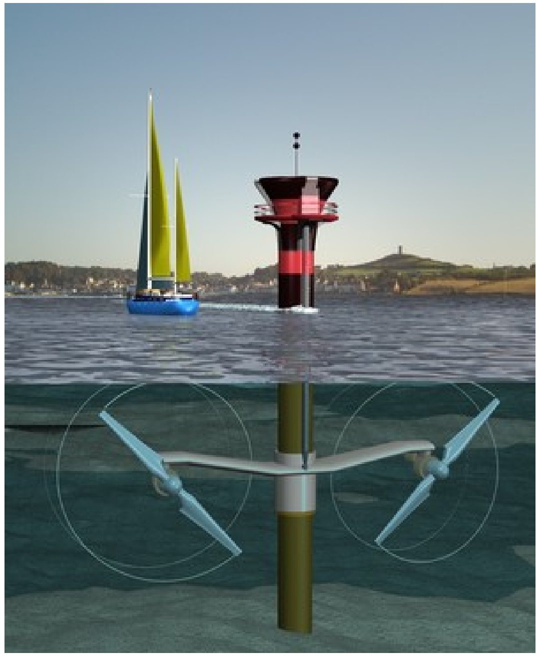
www.tidaltesting.nl



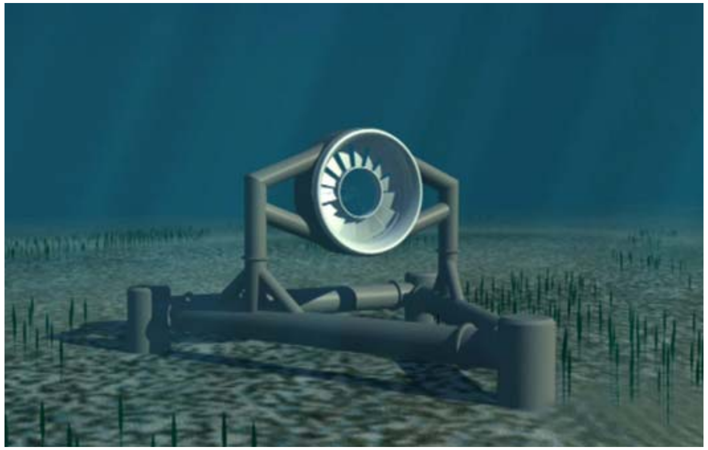
Coastal protection barrage
Experimental site
Den Oever, Hollande

www.tocardo.com
Turbine 45 kW T50

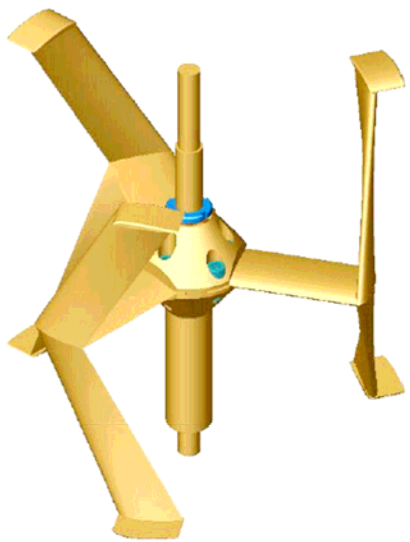
Tidal and current energy



SeaGen (MCT Ltd)



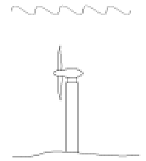
Open Hydro



HARVEST (LEGI)

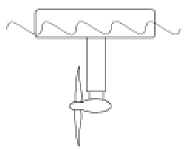
Clean Current

Pile Mounted



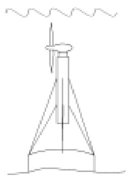
A tower is built on the seabed which supports the rotor at a predetermined depth.

Moored



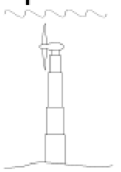
The turbine is mounted underneath a moored, floating platform on the surface.

Guyed Tower



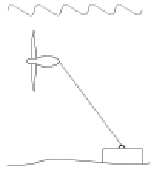
The buoyancy of the nacelle is used to tension multiple chain anchors

Telescopic



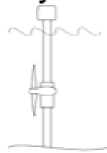
A system of telescopic towers is used to maintain the turbine at the required depth for operation.

Tethered



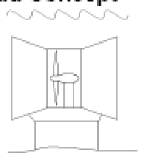
A buoyant system anchored to the seabed via a cable or rigid arm.

Sheath System



Surface piercing tower installed on the seabed. The rotor and generator are mounted on a sheath and moved up and down mechanically.

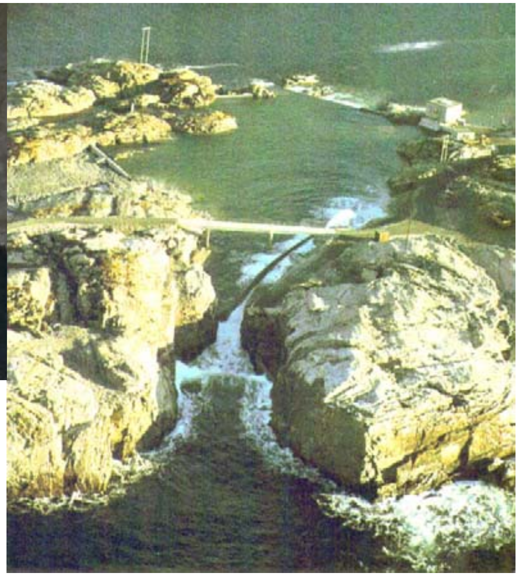
Shroud Concept



A cylindrical shroud or duct surrounds the rotor, the middle section of which can be separated for removal and maintenance. The device weight and use of anchor chains fixes it to the seabed

Tidal and current energy

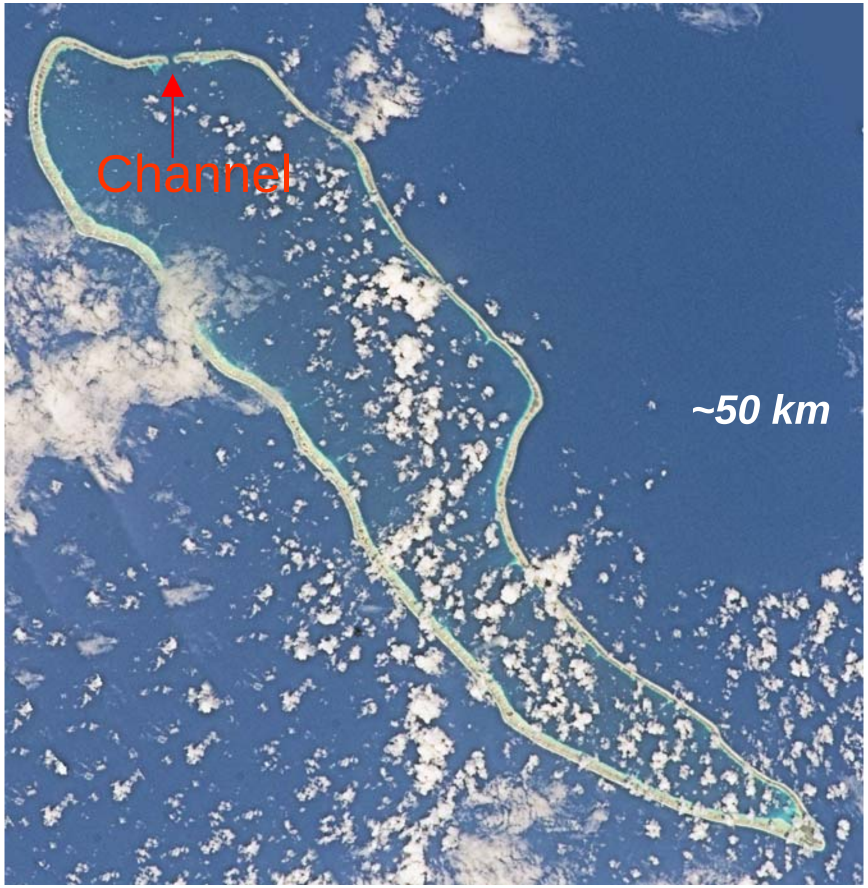
Particular aspects of kinetic energy from currents



Tapchan site (Tapered Channel) near Bergen, Norway

Natural site on Maré island, Loyauté islands (not exploited)

Hao atoll, Tuoamotu archipelago (not exploited)



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Action of the environment and response of the MRE converters

Mechanical Marine Renewable Energy

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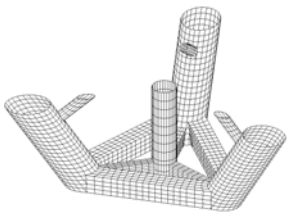
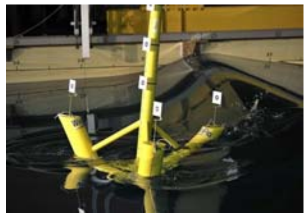
Action of the environment and response of the MRE converters

Action of wind, waves and current is basically modelled by fluid mechanics and fluid structure interaction.
The response can be assessed by three complementary approches : numerical modelling, model testing, full scale observation



Theoretical modelling

Model tests at reduced scale



Full scale at sea

Needs in term of research

Seakeeping scaling effects

Differences between model scale and full scale behaviour is mainly related to the fluid viscous effects, air compressibility if any, power take off modelling.

There is a need for « equivalent » conversion device at model scale to properly model the Power Take Off effects.

Validation of numerical modelling toward model scale tests enables “extrapolation” to full scale.

Return of experience is then needed from full scale trials in order to more precisely assess the calibration of numerical models.

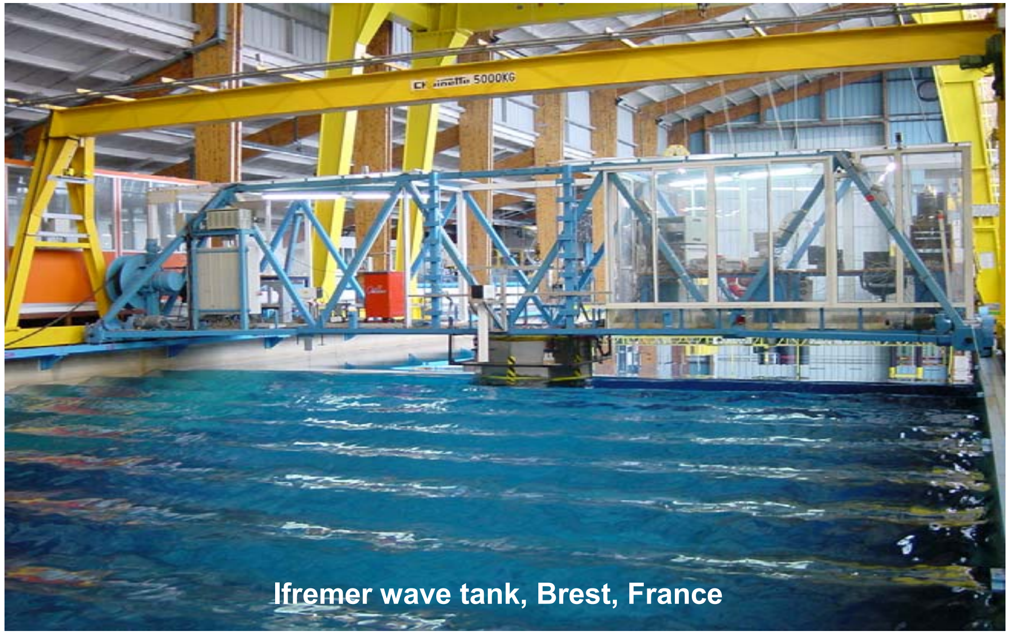
Laboratory and sea trials

The knowledge and assessment of MRE converters design require various trials at different model scales :

- material testing with analysis of ageing in marine environment (tests on samples and at full scale)
- bench testing of electrical systems (scale ~ 1)
- trials in tanks with influence of waves, current and wind (scales >1/50 and preferably ~1/20)
- at sea tests in dedicated sites (scale ~ 1/4 to 1/1)
- resource assessment at sea:
  - wave and current interaction
  - current profile and turbulence
  - wind profile and turbulence
  - measurements techniques (ADCP, HF radar)

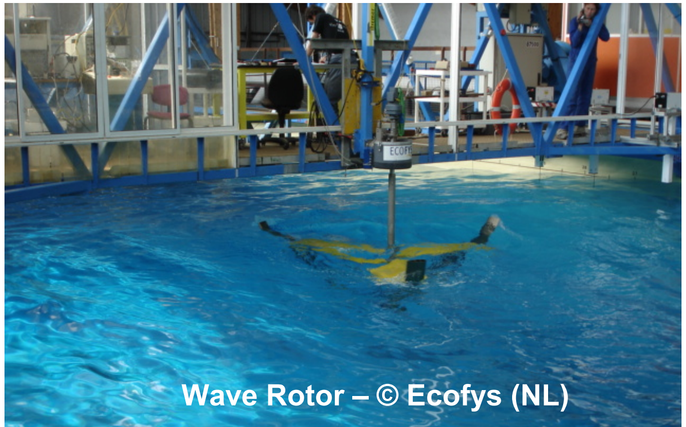
Laboratory trials

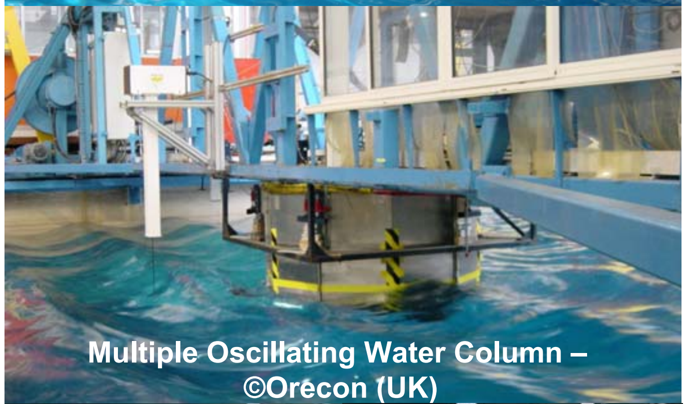
Tank testing at reduced scale

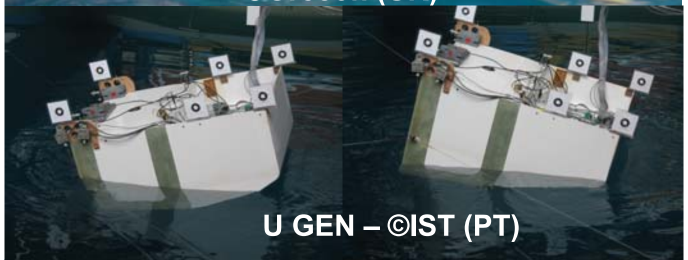


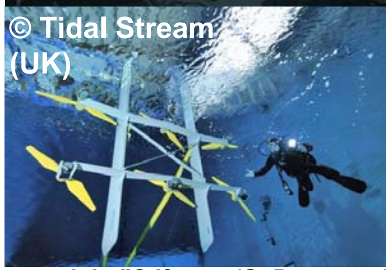
Ifremer wave tank, Brest, France


Generation of wind


Wave Rotor – © Ecofys (NL)


Multiple Oscillating Water Column – ©Orecon (UK)


U GEN – ©IST (PT)


© Tidal Stream (UK)

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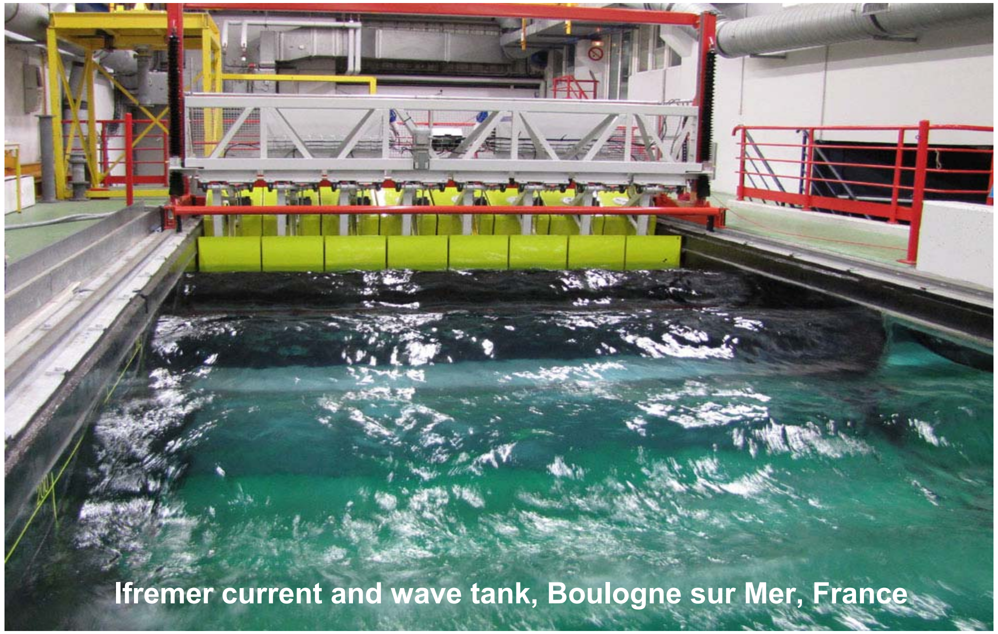
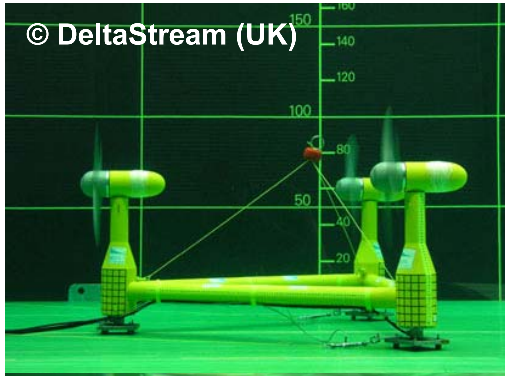
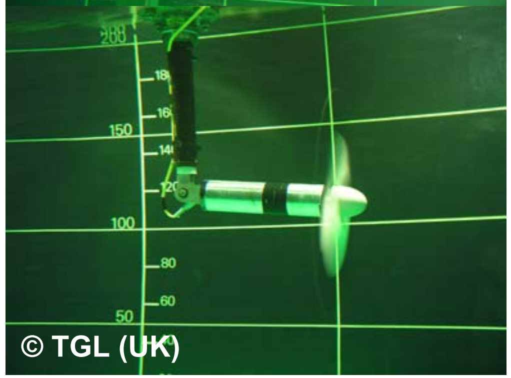
Laboratory trials

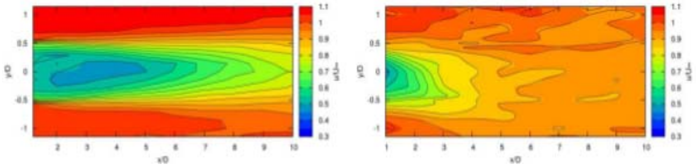
Tank testing at reduced scale



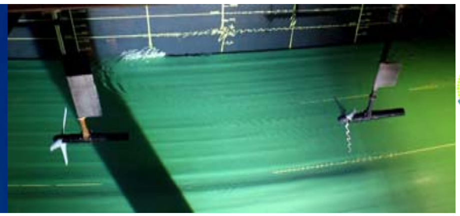


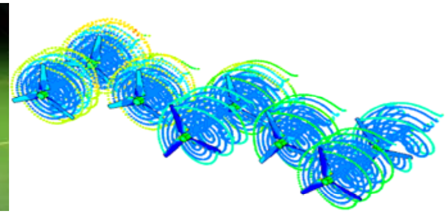


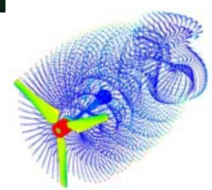
Influence of turbulence on current turbines :



Turbines interaction and wake effects :







Newsletters : wwz.ifremer.fr/manchemerdunord/Technologie-marine/Newsletters

Pacific Economic Cooperation Council

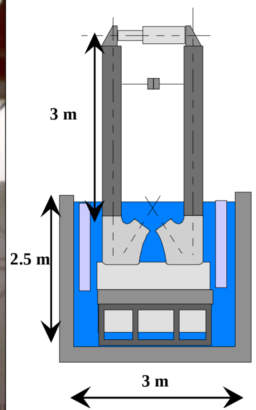
Hawaii, USA, March 26-28, 2012

Laboratory trials

Behaviour and protection of materials and structures in a marine environment

Metallic alloys

- Corrosion phenomena and protection
- Fatigue

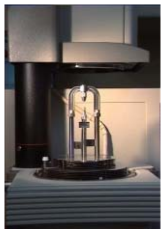


Fatigue test on a piece of an offshore structure

Composites and polymers

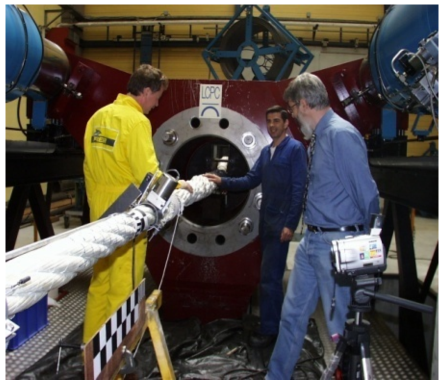
- Evaluation of properties
- Ageing

- Characterisation of synthetic lines



Filament

Yarn 30 T



Rope 450-700T

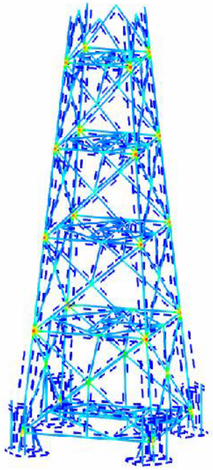
Short term : stiffness - Long term : creep

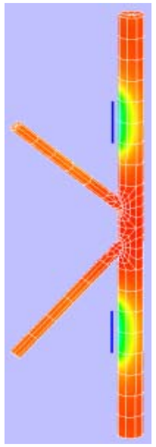
Laboratory trials

Protection against corrosion

Optimisation of the cathodic protection
can be assessed by computation
and laboratory trials.

The result consists on anodes located
on strategic points of the structure.
“Active” anodes have also been developed
assigning given levels of electrical current.

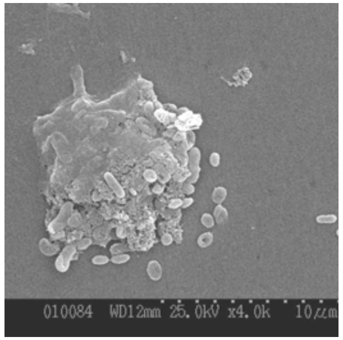




Laboratory trials

Bio-fouling

From the comprehension of bio-film adhesion mechanisms to antifouling methods



Marine bacteria embedded in their exo-polymeric production

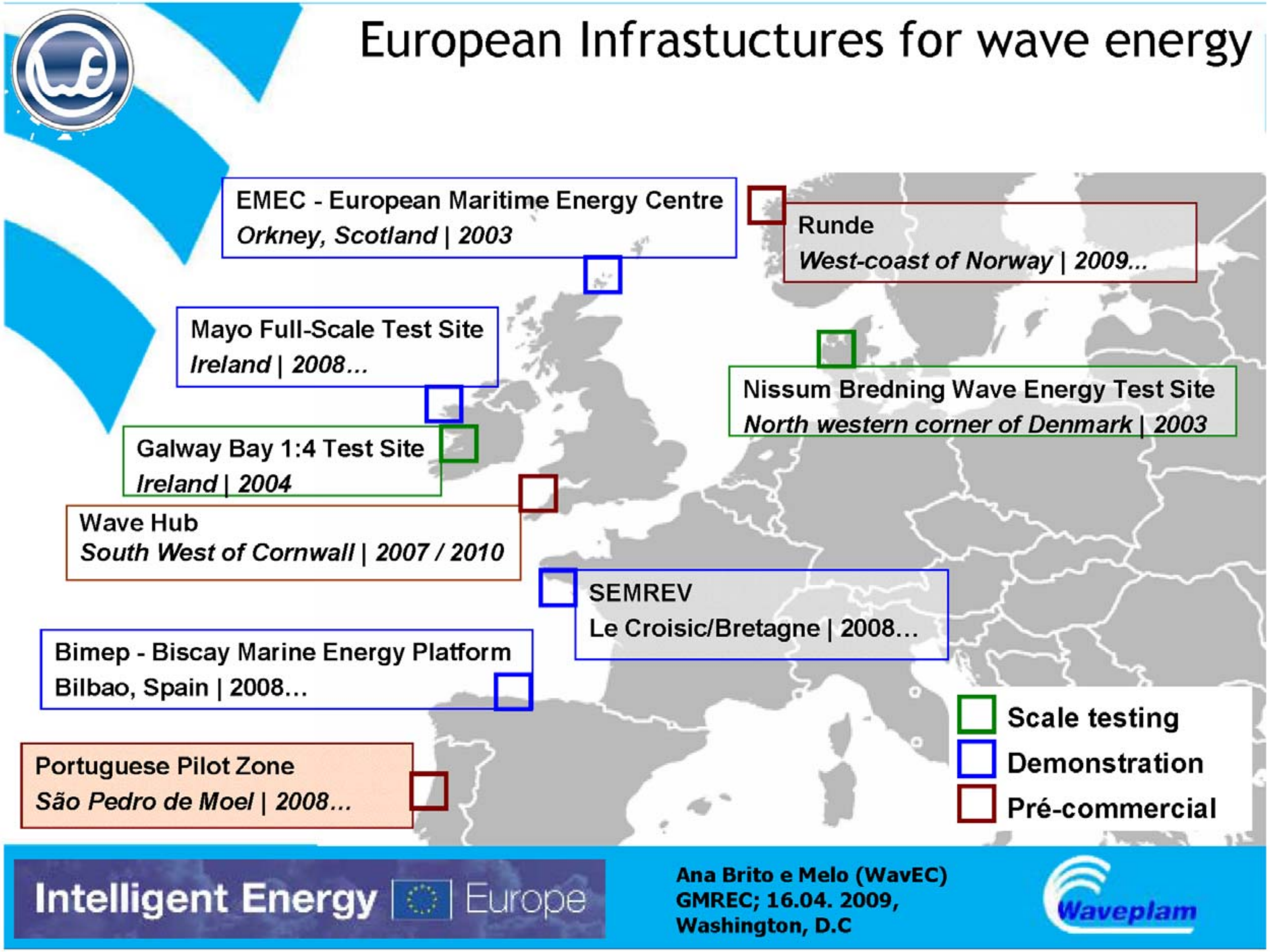
Unprotected port-hole

Protected port-hole

GDR Bio-films Région Bretagne - Europe

Sea trials : test sites

Large scale testing



Pacific Economic Cooperation Council

Hawaii, USA, March 26-28, 2012

Sea trials : test sites

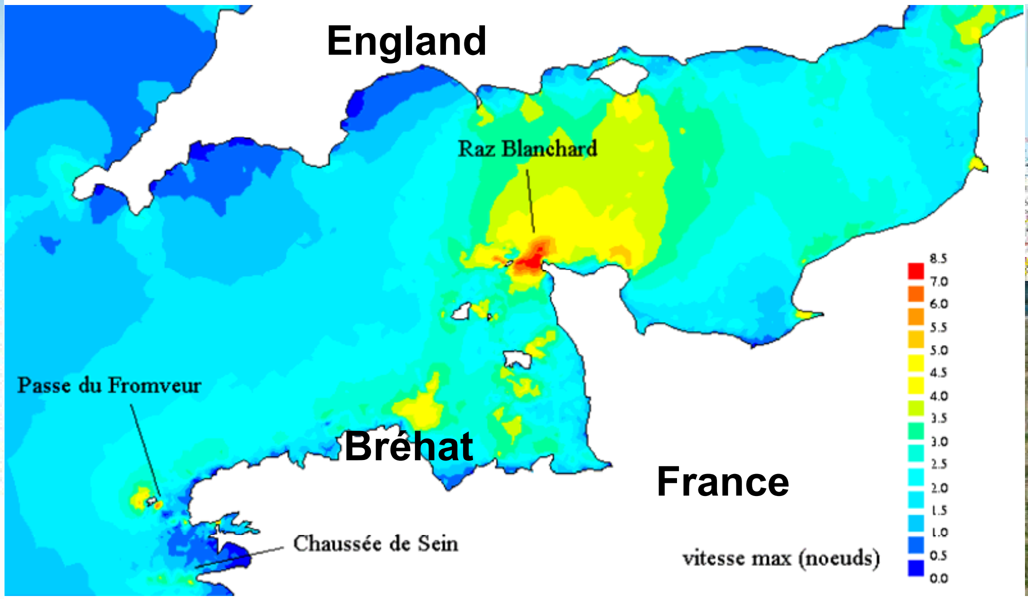
Large scale testing

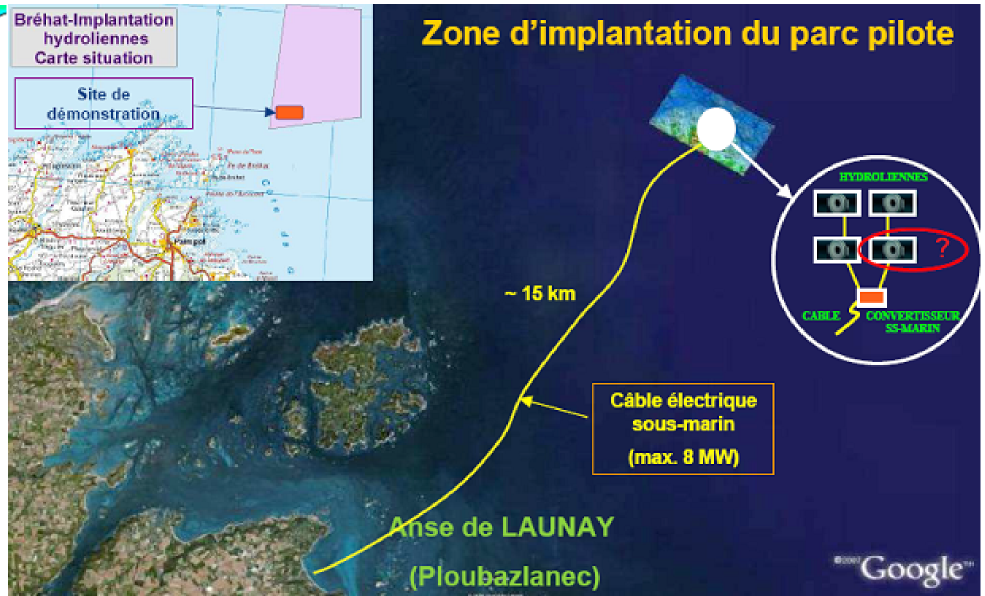
EMEC site, Orkney islands, Scotland
www.emec.org.uk

Marine current turbines

Wave energy converters

Island of Bréhat, France, for marine current turbines





Sea trials : test sites

Large scale to medium scale testing

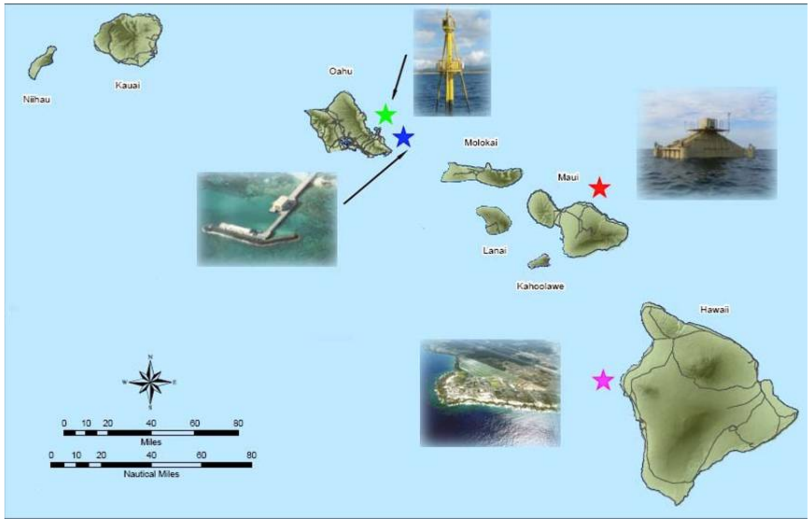
Hawaii National Marine Renewable Energy Center
hinmrec.hnei.hawaii.edu/nmrec-test-sites/

Maui: Establish and maintain a testing site for commercial size wave power systems;

Kaneohe (KMCBH): Expand existing facilities to incorporate a wave-hub providing berthing for as many as four wave energy conversion devices in the 300 to 500 KW range;

Makapu'u: Establish and maintain a testing site for small wave power systems; and, conduct research on corrosion and bio-corrosion of innovative materials;

NELHA: Establish and maintain a testing site for OTEC system components.



Pacific Economic Cooperation Council

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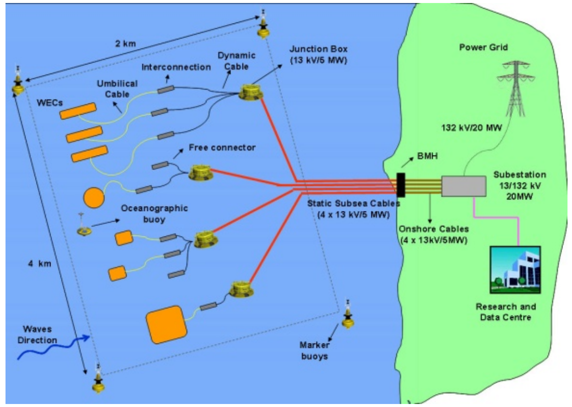
Hawaii, USA, March 26-28, 2012

Ifremer

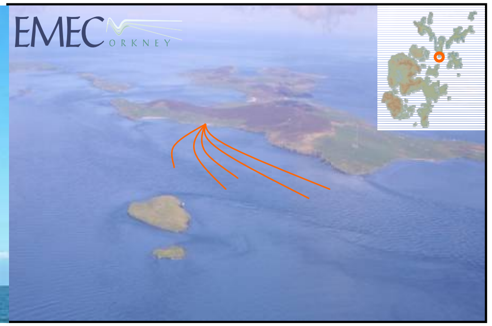
European project MaRINET www.fp7-marinet.eu

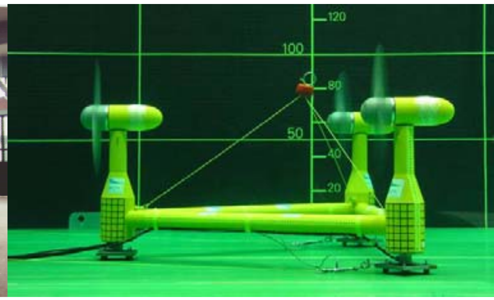
Marine Renewables Infrastructure Network for Energy Technologies

- Coordinated by HMRC
- Consortium of 28 Partners offering 42 Infrastructures
- Wave, Tidal and Offshore Wind
- Systems and components (eg PTO)
- All scales of facilities from model testing to full scale
- Infrastructure Access cost will be paid for by EU to the User (eg a developer)



SEVENTH FRAMEWORK PROGRAMME





Hawaii, USA, March 26-28, 2012

Scale	Structural/Hydrodynamics		Electrical/PTO/ components	Environmental / Databases
	Wave/Wind	*Tidal/Wind*		
Small Lab	o AAU o HMRC – *wind wave* o Edin – *small wave* o QUB – *shallow sea water wave tank* o CRIACIV – *small boundary layer wind tunnel*	o Strat – *tidal towing tank* o RISOE – *Current flume (with carriage)* o Uni Stutt – *Laminar wind tunnel*	o Fh IWES o HMRC o Robotiker – *small rotary rig* o SINTEF – *Grid integration /simulation* o Uni Stutt – *Low head turbine test rig*	N/A
Large Lab	o Nantes - *wind wave* o IFREMER – *deep sea water basin* o NaReC – *wave flume (marine test site)* o LUH – FZK – *Large wave flume in Hydralab proposal* o CNR-INSEAN - *long wave flume with towing*	o IFREMER – *recirculation channel with waves* o CNR-INSEAN – *Recirculation channel hi flow hi volume*	o NaREC – *grid integ. and 3MW rotary rig* o IRFEMER – *materials environmental testing* o RISOE – *Power test lab 30MW offshore Wind*	N/A
Small Site	o AAU Nissum o SEI OEDU - *Galway Bay test site*	o QUB –*Strangford Tidal site* o T.T Centre Neth	o UNEXE – *moorings* o EVE - Mutriku	o SEI MI – *wave & tidal currents site data* o AAU Nissum
Large Site	o EVE – *Biscay Marine Platform* o SEI OEDU - *Belmullet test site* o EMEC	o EMEC	o Fh IWES o Wavec – *Pico plant Azores*	o QUB – *Strangford Data* o EMEC o RISOE – *Mobile offshore wind measuring* o RISOE - *Offshore Wind Database* o ECNeth - *Offshore environmental database* o Uni Stutt – *Offshore nacelle LiDAR* o UoP – *HF Radar for offshore wave/ current*

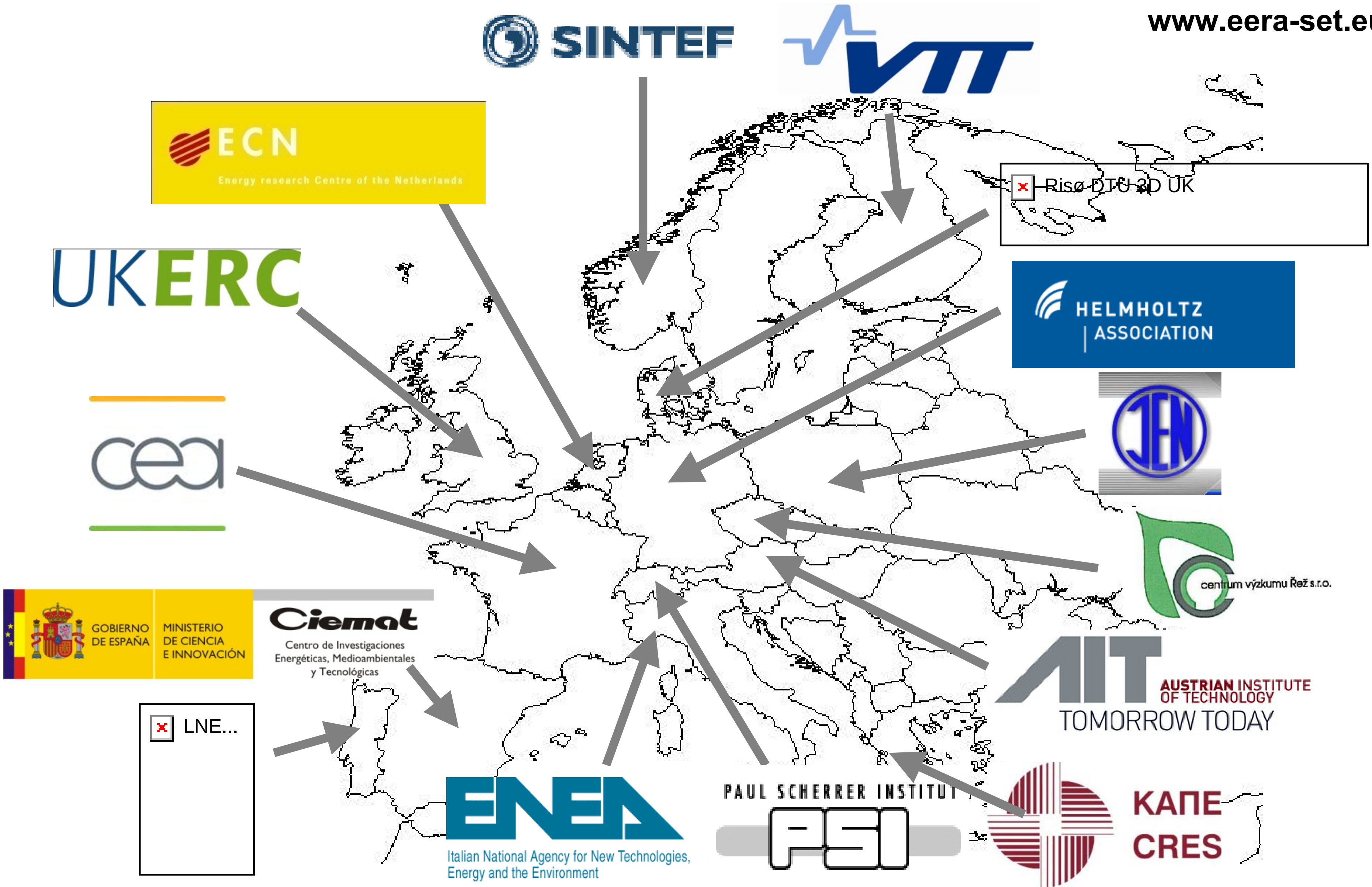
SEVENTH FRAMEWORK PROGRAMME

MaRINET

www.fp7-marinet.eu

European Energy Research Alliance

EERA
European Energy Research Alliance
www.eera-set.eu



www.eera-set.eu

European Energy Research Alliance

EERA European Energy Research Alliance

www.eera-set.eu

EERA objectives:

- Accelerate the development of new energy technologies

- Integration of excellent but dispersed research capacities across the EU

- Strengthen Europe's capacity to initiate and execute large pre-competitive programmes

- Develop links and sustained partnerships with industry to strengthen the interplay between research outcomes and innovation

- Develop training, education and outreach activities

European Energy Research Alliance

EERA Marine Joint Programme

JP coordination : SuperGen Marine - Institute for Energy Systems - UoEdimburgh

Joint Programme Topics and priorities:

1. Resource- UK

2. Devices- Portugal and Norway

3. Deployment and Operations- Spain and Germany

4. Environmental Impact- France

5. Research Infrastructure, Education and Training- Ireland

6. Socio-economic Impact- UK

JP Participants: UK (SuperGen), Spain (Technalia), Portugal (Wavec), France (IFREMER) Italy (ENEA/University of Bologna), Ireland (HMRC), Norway (SINTEF/MARINTEK), Germany (Fraunhofer IWES)

European Energy Research Alliance

www.eera-set.eu

Joint Programme on Wind Energy

JP coordination: Risø DTU

Joint Programme Topics and priorities

1. Wind Conditions. Coordinated by Risø DTU, Denmark

2. Aerodynamics. Coordinated by ECN, The Netherlands

3. Offshore Wind Energy. Coordinated by SINTEF, Norway

4. Grid Integration. Coordinated by FhG IWES, Germany

5. Research Infrastructures. Coordinated by CENER, Spain

JP participants: CENER / CIEMAT (Spain), CRES (Greece), ECN (Netherlands), FhG IWES (Germany), LNEG / University of Porto (Portugal), Risø DTU (Denmark), SINTEF (Norway), VTT (Finland) and the University of Strathclyde (UK)

Mechanical Marine Renewable Energy Technological barriers

Construction of large scale and fine mesh metocean database

Development of numerical tools: seakeeping, energy conversion

Design of mooring systems

Materials: reliability, fatigue, corrosion, bio-fouling, life cycle

Operations at sea: deployment, inspection, maintenance, reparation, dismantling

Connexion to the grid: underwater connectors, umbilicals

Energy storage: batteries, hydraulic, hydrogen?

Evolution of standards: classification society criteria

Industry process: use of existing infrastructures and skills, upgrading

Mechanical Marine Renewable Energy Multidisciplinary field for research and development

Marine renewable energy conversion benefit from acquired knowledge in the fields of marine technology, ocean engineering, oil and gas industry, electrical engineering.

Both academic and technical disciplines are involved in the design process of marine renewable energy converters :

- Physical oceanography, meteorology
- Fluid mechanics and hydrodynamics
- Materials and structures, chemistry
- Electrical engineering
- Thermodynamics
- Geotechnics
- Acoustics

Thank you for your attention

Marc.Le.Boulluec@ifremer.fr