EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

MARINE BOARD

Marine Board
Vision Document 2

October 2010

Marine Renewable Energy

Research Challenges and Opportunities for a new Energy Era in Europe

The Vision

"By 2050 Europe could source up to 50% of its electricity needs from Marine Renewable Energy. This would have a profound impact on the European economy and European citizens. It would contribute to energy supply and security, reduce CO_2 emissions and their impact on the oceans, improve the overall state of the environment, improve quality of life, create jobs in a range of innovative sectors and herald a new era of environmentally sustainable development."

This Vision is achievable and the potential rewards are considerable. It will rely on political commitment, public support, the establishment of a European offshore energy grid and a supportive fiscal and planning regime. **Crucially, it will also require sustained research to feed both innovation and concept demonstration, and to develop appropriate environmental monitoring protocols.**

www.esf.org/marineboard

This Marine Board Vision Document on Marine Renewable Energy:

- Presents a vision for the development of Marine Renewable Energy in Europe (cover, page 5);
- Highlights the potential of Marine Renewable Energy in Europe and identifies the challenges and opportunities associated with this new and innovative sector (page 4);
- Identifies the research needs to realise this potential (page 6-11); and
- Aims to secure Marine Renewable Energy on the European marine research agenda (page 3).

Contributing Authors

- Augusto Barata da Rocha, *INEGI, Portugal*
- Cibran Camba Rey, *Acciona Energia, Spain*
- Marc Le Boulluec (Chair), *Ifremer, France*
- John Dalen, *Institute of Marine Research, Norway*
- Henry Jeffrey, *Energy Research Council, UK*
- Finn Gunnar Nielsen, *Statoil and University of Bergen, Norway*
- Geoffrey O'Sullivan, *Marine Institute, Ireland*
- Nathalie Rousseau, *European Ocean Energy Association*
- Eoin Sweeney, *Sustainable Energy Ireland, Ireland*
- Judith Wolf, *National Oceanography Centre, UK*

Series editor
Niall McDonough, *Marine Board-ESF*

Editorial support
Maud Evrard, *Marine Board-ESF*

External reviewer
John Huckerby, *Aotearoa wave and tidal energy association, New Zealand*

Acronyms
CO_2: Carbon Dioxide
EC: European Commission
EDF: Electricité de France
EMEC: European Marine Energy Center
ESF: European Science Foundation
EU: European Union
EU-OEA: European Ocean Energy Association
EWEA: European Wind Energy Association
MB: Marine Board
MRE: Marine Renewable Energy
OTEC: Ocean Thermal Energy Conversion
R&D: Research and Development
UKERC: United Kingdom Energy Research Centre.
WEC: World Energy Council

Units
g: gramme
m/s: metre per second
t: tonnes
Mt: Megatonne (10^6 tonne – 1 million tonnes)
W: watt
kW: kilowatt (10^3 watt)
MW: Megawatt (10^6 watt)
GW: Gigawatt (10^9 watt)
TW: Terawatt (10^{12} watt)

MARINE BOARD

The work was initiated and facilitated by the Marine Board. The Marine Board provides a pan-European platform for its member organisations to develop common priorities, to advance marine research and to bridge the gap between science and policy, in order to meet future marine science challenges and opportunities.

The European Science Foundation (ESF) provides a platform for its Member Organisations to advance science and explore new directions for research at the European level. Established in 1974 as an independent non-governmental organisation, the ESF currently serves 79 Member Organisations across 30 countries.

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High level recommendations

Securing Marine Renewable Energy on the European marine research agenda

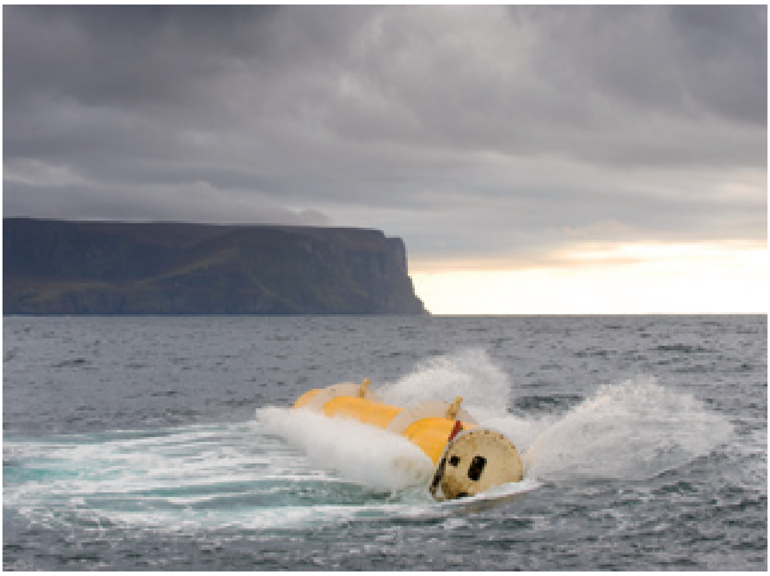
Marine Renewable Energy can be a significant contributor to energy needs in Europe. In the next decade, this will require:

- Research efforts in Europe to be intensified and better coordinated across relevant sectors, disciplines and regional, national and European programmes, with particular attention to developing cost-efficient energy production techno-logies and appropriate environmental monitoring protocols.
- Marine Renewable Energy research to be specifically prioritised for support and targeted funding in Framework Programme 8 (from 2014) and future European Joint Programming activities.
- Improved coordination between industry needs and research efforts e.g. through the joint development of a Strategic Research Agenda for Marine Renewable Energy and the development of collabora-tive networks of researchers and technology developers.
- A comprehensive, consistent and integrated assessment of Marine Renewable Energy resources (i.e. offshore wind, wave energy, tidal range and current, ocean current, salinity gradient, thermal gradient and marine biomass) in Europe; i.e. the mapping of Europe's Marine Renewable Energy resources.
- Appropriate education, training and outreach mechanisms to ensure public and stakeholder support and focused third-level training opportunities to provide the skilled workforce necessary to service the expanding Marine Renewable Energy sector.
- A pro-active, visionary and supportive European policy on Marine Renewable Energy.
- A governance framework relying on sound research and based on:
  - The development and consolidation of enabling policies (e.g. a European energy market);
  - The alignment of potentially competing policy objectives;
  - The provision of key supporting infrastructures, including test and demonstration sites and a European offshore energy grid interconnector; and
  - The positioning of Marine Spatial Planning at the core of the sustainable development of Marine Renewable Energy in Europe.

"Europe must prepare the ground for a 100% renewable energy future, starting today. ... a 100% renewable energy supply system by 2050 ... is not a matter of technology, but rather a matter of making the right choices today to shape tomorrow."

Prof. Arthouros Zervos
President, European Renewable Energy Council, 2010

Figure 1: The first full-scale Oyster 1 wave power device in operation off Orkney coastline, Scotland



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Marine Renewable Energy
Definition

Renewable Energy resources may be categorised in different ways as illustrated in Figure 2. Simply put, Renewable Ocean Energy is a subset of Marine Renewable Energy which is, in turn, a subset of Renewable Energy as a whole.

Marine Renewable Energy is defined, for the purposes of this Vision Document, as Renewable Energy production which makes use of marine resources or marine space. In general terms, Marine Renewable Energy devices utilise marine space, share many converging technologies and energy management systems, are installed, operated, maintained and decommissioned at sea and need access to offshore grid and distribution systems. It is reasonable and indeed essential to address them collectively here.

Figure 2: Renewable Energy resources and categories

Renewable Energy

- Onshore wind
- Hydro energy
- Solar energy
- Geothermal
- Bioenergy

Marine Renewable Energy

- Offshore wind
- Marine biomass (micro- and macro-algae)

Renewable Ocean Energy

- Wave
- Tide (current and range)
- Ocean current
- Osmotic gradient
- Thermal gradient

Marine Renewable Energy
Challenges and opportunities

For Marine Renewable Energy in Europe, the challenges are significant...

- Recognition of Marine Renewable Energy as a legitimate and desirable use of ocean space along with other sectors such as shipping, fishing, aquaculture, recreation and conservation.
- The controlled expansion of Marine Renewable Energy based on appropriate Strategic Environmental Assessments and managed within the context of a Marine Spatial Planning framework.
- A comprehensive research programme to consistently improve the technical and economic performance of Marine Renewable Energy devices whilst also tackling potential environmental impacts.
- The development of a European energy market, a European energy grid and agreed international standards and certification for Marine Renewable Energy systems.
- A proactive, supportive and stable governance, financial and regulatory policy towards Marine Renewable Energy.

... but the rewards are high:

- Significant improvement in energy security and reduced dependence on energy imported from outside Europe.
- Creation of a new internal and export market for Marine Renewable Energy products and services.
- Significant environmental benefits including improved air quality and reduction in CO_2 and other greenhouse gas emissions.
- Creation of new economic opportunities and employment.
- Opportunities for European science and technology to be at the forefront of the design, construction, operation, maintenance and decommissioning of Marine Renewable Energy devices.

"The EU currently imports approximately 55% of its energy – and might reach 70% in the next 20 to 30 years."

European Commission – Eurostat (2009)
& European Commission (2006)

Marine Renewable Energy

A Vision and a partnership

A striking Vision...

The Visionary Statement “*By 2050 Europe could source up to 50% of its electricity needs from Marine Renewable Energy*” is estimated on the basis of projections made by authoritative bodies, e.g.:

- Offshore wind could meet between 12.8% and 16.7% of total EU electricity demand by 2030 (EWEA, 2009);
- Renewable Ocean Energy could meet 15% of EU energy demand by 2050 (EU-OEA, 2010).

These projections were, in turn, based on assumptions related to e.g.:

- Global fossil fuel prices;
- European macroeconomic state;
- European energy policy initiatives (e.g. nuclear policy, renewable policy) and targets; and
- Potential advances in marine energy conversion technologies.

... for a coordinated approach:

The sustainable and successful development of Marine Renewable Energy will rely on co-ordinated action from the research, industry and policy sectors. In this respect, the coming decade (2010-2020) will be crucial. The research agenda to deliver the proposed vision will both drive and be driven by policy and industry developments as illustrated in Figure 3.

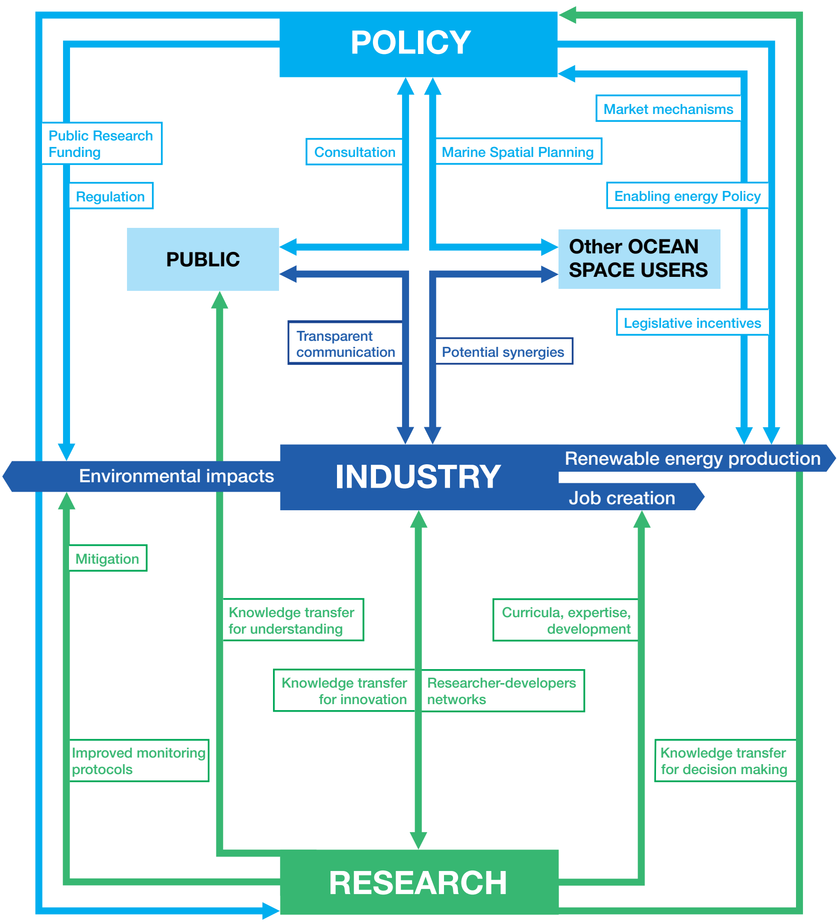


Figure 3: The sustainable development of Marine Renewable Energy in Europe must be based on a partnership.

Marine Renewable Energy resources…

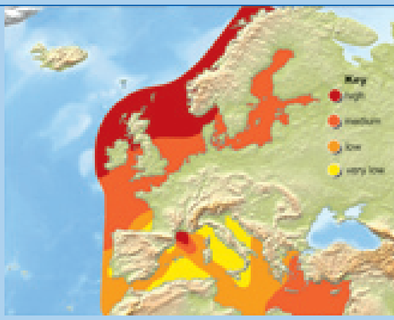
<table>
<tr><th></th><th>OFFSHORE WIND</th><th>WAVE</th></tr>
<tr><td>Definition</td><td>Offshore wind is the movement of air above the seas and oceans, the kinetic energy of which can be harnessed by wind turbines (see Figure 4).</td><td>Waves are formed by wind blowing over water and occurring in water near the sea surface. Kinetic and potential energy associated with ocean waves can be harnessed using modular technologies (see Figure 6).</td></tr>
<tr><td>Resource</td><td>
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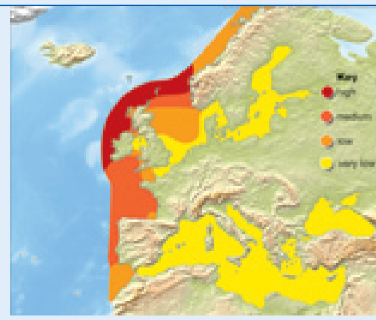
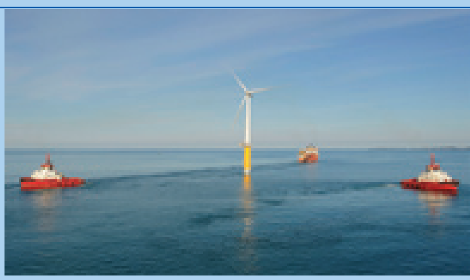
Figure 4: Offshore winds are stronger and steadier than on land. Strongest offshore wind locations are off the coastlines of Norway, UK and Ireland</td><td>
© AquaRET
Figure 6: Prime European locations for wave energy are off the coastlines of UK, Ireland, Norway, Portugal, Spain and France</td></tr>
<tr><td>Electricity production</td><td>The projected electricity production from offshore wind by 2030 is 563TWh per year (EWEA, 2009).</td><td>The projected electricity production from wave energy by 2040 is 142TWh per year (EU-OEA).</td></tr>
<tr><td>Energy converter (example of)</td><td>
© Øyvind Hagen / Statoil
Figure 5: Hywind being towed to its anchoring site off the island of Karmøy, Norway</td><td>
© Wave Dragon
Figure 7: Wave Dragon - a floating, slack-moored energy converter off Nissum Bredning, Denmark</td></tr>
<tr><td>Research priorities</td><td>At present, there is no difference of approach in the development of onshore and offshore wind energy exploitation. However, in the near future, the technologies and the resource evaluation and installation methods will diverge in response to the different requirements for offshore and nearshore environments.

Future research must target inter alia:
• Meeting the design needs to facilitate the location of wind farms in deeper water and further offshore.
• Addressing critical technology challenges, e.g. development of new substructures with reduced weight, possibly floating and reduced maintenance requirements (see Figure 5).
• Investigating the interaction between waves and (floating or moored) structures, and the optimum positioning of wind turbines within an array.</td><td>To date more than one hundred wave energy concepts are being considered worldwide (EMEC), with many still at the R&D stage. The technology will fully mature over time and will strive towards the development of systems which will be efficient in extreme conditions.

Future research must target inter alia:
• Improving computational tools in order to better tackle the large motions and strongly non-linear behaviour of wave energy absorbers.
• Optimising control systems upon which wave energy devices rely to work efficiently in various sea states.
• Conducting wave climate forecasting (short-, medium- and long-term).
• Improving device responses to wave grouping and multidirectionality.</td></tr>
</table>

… with strong potential for Europe by 2020

Definition

TIDE

Tides are the rise and fall of sea levels caused by the gravitational forces exerted by the moon and the sun. Tidal impoundment can generate electricity by holding back the tide. When there is a sufficient head of water, the flow is allowed to pass through turbines.

TIDAL and OCEAN CURRENTS

Kinetic energy present in tidal (ocean) currents can be turned into electricity by using modular turbine systems, which can be placed directly in-stream to generate power from the flow of water (see Figure 10).

Resource

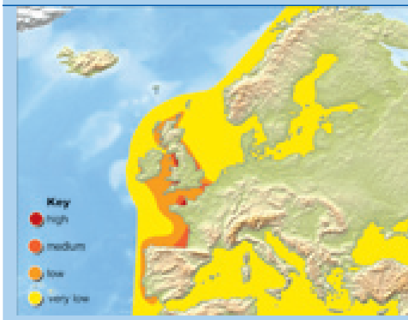


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Figure 8: In Europe, the highest tidal ranges can be found in the UK and France.

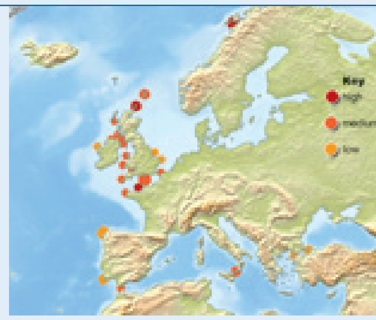

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Figure 10: High tidal streams are very site specific.

Electricity production

The world's largest operational tidal barrage, La Rance, France, produces **0.54TWh per year** (EDF). The planned UK Severn Barrage could produce **17.1TWh per year** (WEC, 2001).

Tides, tidal and ocean currents could produce **36TWh per year** by 2040 (EU-OEA).

Energy converter (example of)

© Clipper

Figure 9: La Rance barrage, France

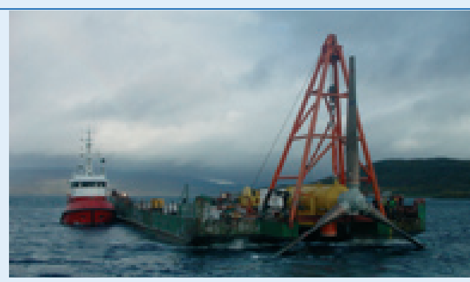

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Figure 11: Installation of tidal turbine

Research priorities

Future research must target *inter alia*:

- Investigating the sustainability of moving beyond the strict geographical walls of tidal estuaries and basins, for example, artificial offshore impoundment schemes could be built on tidal flats in areas with high tidal range.

As with wave energy, this is still an emerging resource option and no specific technologies have yet emerged as the definitive winners. More conversion concepts can be expected in future.

Future research must target *inter alia*:

- Exploiting low flows - presently a minimum flow of 2.5m/s is required for economically viable energy generation.
- Understanding the nature of the total flow environment and assessing the energy delivery potential of a particular site.
- Modelling water flow in channels and headlands, and device response in the presence of water flow, using computational fluid dynamics.
- Designing new turbines for both tidal and ocean currents.

One kilowatt-hour (kWh):

- **is consumed in six hours by the average EU citizen (equivalent to 1,460kWh per year);**
- **creates around 420g of CO_2 (with the current EU electricity mix);**
- **is produced by a big wind power plant in one second during a strong breeze.**

European Commission (2010)

Other Marine Renewable Energy resources

	OSMOTIC GRADIENT	THERMAL GRADIENT	MARINE BIOMASS
Definition	Osmotic pressure builds up when two aqueous solutions are separated by a semi-permeable membrane. The water with low salt concentration moves to the side with the higher salt concentration. Thus creating a pressure differential which can be used to drive a turbine.	Thermal energy (based on the temperature gradient between the sea surface and deepwater) can be harnessed using different Ocean Thermal Energy Conversion (OTEC) processes.	Marine Biomass, in the context of Marine Renewable Energy, refers to the use of micro- and/or macro-algae for biofuel production.
Technology	European researchers have been exploring novel approaches to exploit salinity gradients for energy production. The main challenges relate to membrane design. (see Figure 12).	Most of the technology developments remain at the planning/feasibility study stage, since the capital cost of installation is extremely high. The main research and development challenges relate to the design of heat exchanger and underwater tubes.	Genomics and eco-physiology as well as the control of key parameters (e.g. temperature, irradiance, pH, and nutriments) are key to the production of biodiesel from micro-algae. Intensive production with photo-bioreactors is more expensive but allows for more control.[1]
Resource	Given the significant amounts of freshwater entering the sea from European rivers, the osmotic gradient could support the production of **28TWh per year** by 2040 (EU-OEA).	The global technical resource exploitable with today's technology is estimated to be in the order of 33,000TWh per year (Isaacs and Schmitt, 1980). European overseas territories located close to the Equator (e.g. Guadeloupe, New Caledonia, French Polynesia) have access to such resources.	Micro-algae species number between 200,000 and several millions with a huge research and industrial potential and may be used in the production of biofuel.

1. See also **Marine Board Position Paper 15 (2010)**. *Marine Biotechnology: A New Vision and Strategy for Europe.*

© StatKraft

"Renewable Ocean Energy could avoid the emission of 136Mt of CO_2 per year by 2050."

European Ocean Energy Association (EU-OEA, 2010)

Figure 12: Membranes roll made from polymer

Environmental challenges and opportunities

Understanding and monitoring the environmental impacts of Marine Renewable Energy

Because Marine Renewable Energy is in its infancy, there is limited data or knowledge on the medium- and long-term environmental impacts of Marine Renewable Energy devices. Studies have been conducted to identify key environmental factors and potential (cumulative) impacts which will need to be investigated and monitored during the installation and lifetime of commercial devices (see Table 1).

Environmental factor	Potential impacts
Water circulation patterns	Alteration of water circulation and sediment transport patterns
Benthic habitats	Physical and biological disturbance of the seabed, flora and fauna
Artificial reef effect	Effect of solid structures on the seabed as enhancers of biomass around the area
Water quality	Effects of biofouling removal operations or the use of antifoulants
Sound disturbance	Behavioural responses of marine animals to underwater sound from energy devices
Electromagnetic fields	Impacts on different ecological groups and at different life-cycle stages
Avoidance behaviour	Dynamics of avoidance and collision of marine animals with devices at sea
Light disturbance	Biological significance of behavioural responses to flashing light from rotor blades

Table 1: Some potential environmental impacts of Marine Renewable Energy devices – Adapted from: *Uncertainties regarding environmental impacts [of wave and tidal energy devices]. A Draft.* (Equimar - FP7-213380, 2009)

Future research efforts must target *inter alia*:

- Defining national and international environmental protocols and guidelines (e.g. Strategic Environmental Assessments, Environmental Impact Assessments) in collaboration with public authorities and stakeholders in order to assist both developers and regulators in the design and approval of licensing and environmen-tal monitoring frameworks.
- Developing a better understanding of environmental impacts and responses to commercial-scale installations and predicting the cumulative environmental interactions of scaling-up to large offshore device arrays.
- Developing new cost-effective environmental monitoring devices (e.g. bird detection radar) to be embedded in the automatic monitoring of devices, especially for remote offshore installations.
- Developing mitigation measures both specific to identified environmental impacts, and to each device type in line with technological and design evolution.
- Turning the environmental factor into a competitive advantage through the development of new marketable technologies and processes for impact monitoring and mitigation.
- Contributing to the development of standards and testing protocols, and strengthening the role of testing centres in Europe as centres for practical R&D related to both technology development, and environmental monitoring and measurement.

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Figure 13: Monitoring catch at Nysted offshore wind farm, Denmark

Technology and innovation

Making Marine Renewable Energy sustainable and mainstream

Deployment and infrastructure challenges face the emerging Marine Renewable Energy sector; they can be classified in terms of predictability, manufacturability, survivability, installability, affordability, and reliability (UKERC). Technology developments will need to focus on:

- Optimising device design to achieve low-cost energy production, to minimise maintenance and to maximise life-span;
- Transforming energy from devices to usable electricity linked to national grids;
- Measuring, monitoring and mitigating environmental impacts.

In partnership with the industry, **future research efforts must target *inter alia*:**

- Improving resource predictions for planning purposes and also for operational efficiency (i.e. balancing power production and consumption), assessment of marine energy resources, and providing open access databases and real-time information on ocean climate and related environmental parameters.
- Designing and developing:
  - Innovative robust device construction materials;
  - Large scale (arrays of) devices efficiently installed, operated and decommissioned;
  - Wind-wave and wind-tidal current hybrid systems, bringing added-value to offshore wind projects, combining installation and maintenance costs and sharing grid connection;
  - Vessels (e.g. with dynamic positioning systems, improved sea-keeping and manoeuvrability) for operations throughout device life-cycles, and the potential for construction and use of artificial offshore harbours (see Figure 16).
- Improving energy management and storage devices (e.g. batteries).
- Contributing to the establishment of an integrated European transnational offshore grid (including smart metering) supporting intermittent power supply.

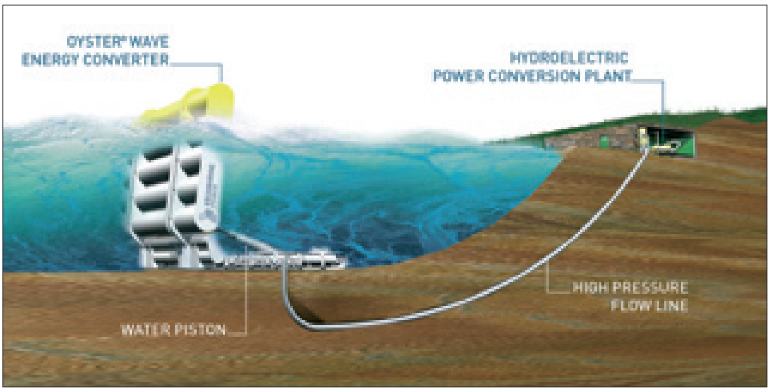

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Figure 14: The Oyster hydro-electric wave energy converter is a buoyant, hinged flap designed to be attached to the seabed and to sway backwards and forwards in near-shore waves.

Public perception

Public knowledge and support for Marine Renewable Energy

Local communities, the general public and other stakeholders must be engaged in discussions and communication prior to commercial deployments of the Marine Renewable Energy devices. In this way the opportunities, constraints and risks presented by Marine Renewable Energy can be communicated and all stakeholders can input the process.

Future research efforts must target *inter alia*:

- Investigating the social impacts of expanding Marine Renewable Energy (e.g. effect of the devices on the seascape value).
- Developing standards for the harmonisation of regulations, safety, testing, certification, education and training.

Job creation and training

Delivering sustainable jobs for a smart European economy

The manufacture, transportation, installation, operation and eventual decommissioning of Marine Renewable Energy devices will generate employment, particularly in coastal communities, many of which are in remote, low employment areas or experiencing a decline of traditional activities (e.g. fishing, shipbuilding). This will meet the requirements for smart sustainable and inclusive growth set out in the Europe 2020- A strategy for smart, sustainable and inclusive growth (COM(2010) 2020).

Projections suggest that:

- By 2050, the Renewable Ocean Energy sector could provide 470,000 jobs, which corresponds to 10 to 12 jobs (direct and indirect) created per megawatt installed (EU-OEA, 2010).
- By 2030, employment in the offshore wind sector could provide 226,000 jobs, 60% of the total employment in wind energy (EWEA, 2009).

Future research and education efforts must target *inter alia*:

- Developing new areas of expertise in engineering, construction, navigation, ecology, and marine environmental monitoring in order to supply the Marine Renewable Energy sector and ancillary businesses with skilled workers and specialists.

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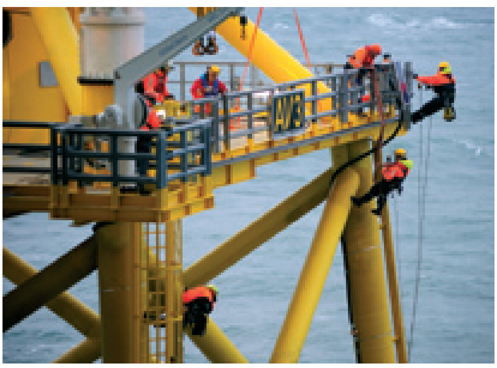

Figure 15: Working onboard an offshore windmill

Marine Spatial Planning

Positioning energy as a legitimate use of the ocean space within coordinated planning frameworks

The development of a European Marine Renewable Energy sector will compete for space with other legitimate uses of the sea including fisheries, aquaculture, maritime transport, recreation and conservation. To minimise and manage potential conflicts, comprehensive Marine Spatial Planning frameworks must be established. The independent management of marine space, with fair allocation of resources and transparent participatory procedures for assessment, planning, licensing and monitoring structures, is crucial for the sustainable development of the sector.

Future research efforts must target *inter alia*:

- Assessing socio-economic impacts concerning competition for space and resources.
- Facilitating the use of multi-purpose offshore platforms for Marine Renewable Energy generation and a range of other potential uses including aquaculture, marine environmental monitoring, coastal defence and road crossings (barrages).

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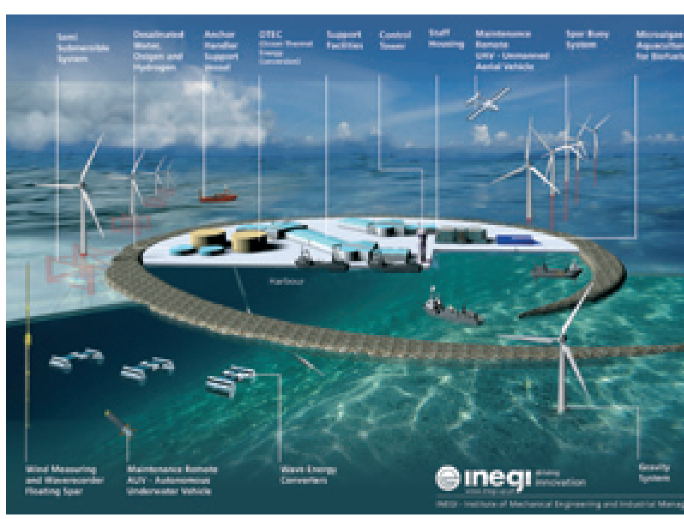

Figure 16: Visionary concept of an offshore energy harbour

Marine Board Member Organisations

European Science Foundation
SETTING SCIENCE AGENDAS FOR EUROPE

MARINE BOARD

Wandelaarkaai 7 | 8400 Ostend | Belgium
Tel: +32 59 34 01 63 | Fax: +32 59 34 01 65
marineboard@esf.org
www.esf.org/marineboard

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