IEA-OES

ANNUAL REPORT 2008

International Energy Agency
Implementing Agreement
on Ocean Energy Systems

IEA | OES
Ocean Energy Systems

IEA-OES

ANNUAL REPORT 2008

International Energy Agency
Implementing Agreement
on Ocean Energy Systems

IEA | OES
Ocean Energy Systems

2008 ANNUAL REPORT – IEA-OES DOCUMENT A08

PUBLISHED BY the Executive Committee of the IEA-OES

EDITED BY A. Brito-Melo and G. Bhuyan

DESIGNED BY P-06 ATELIER E AMBIENTES E COMUNICAÇÃO LTD

CIRCULATION 1000 EXEMPLARS

PRINTED BY TEXTYPE

THE SUGGESTED CITATION OF THIS REPORT IS

2008 Annual Report, International Energy Agency Implementing Agreement on Ocean Energy Systems (IEA-OES), edited by A. Brito-Melo and G. Bhuyan, February 2009.

Contents

Chairman's Message

Welcome to the Annual Report of the IEA Implementing Agreement on Ocean Energy Systems (IEA-OES) for the year 2008. The report provides an overview of activities of the Executive Committee of the IEA-OES and its member/observing countries to enable the deployment of technologies worldwide for harnessing all forms of ocean renewable energy resources, such as, tides, waves, marine currents, thermal gradients and salinity gradient to generate electricity and for other uses. I am very pleased to report the progress in our portfolio and the continuing growth in participation.

Interest in IEA-OES membership continues. Four new member countries, Spain, New Zealand, Italy and Sweden, joined the Implementing Agreement in 2008. The governments of France and Australia have also decided to join the agreement. Brazil and South Africa are at an advanced stage of their internal process for becoming the members of the IEA-OES. India, Australia, Netherlands, Korea, Chile and China were invited by the Executive Committee in 2008 to join the implementing agreement.

In order to enhance the technology development and deployment collaboration with Russia, a representative of the IEA-OES participated in the IEA Networks of Expertise on Energy Technologies (NEET) workshop held in Moscow.

Over the past year, tremendous activity in information exchange and dissemination has taken place, including the successful completion of an information DVD for various stakeholders. Many thanks to Mr. Gary Shanahan from the United Kingdom, Prof. Antonio Falcão from Portugal, Prof. AbuBakr Bahaj from the United Kingdom, Prof. Gérard Nihous from the United States, Mr. Øystein S. Skråmestø and Mr. Stein Erik Skilhagen from Norway, and Dr. Purnima Jalihal and Dr. S. Kathiroli from India for their valuable contributions to this annual report discussing potential and developmental status of technologies for harnessing power from tidal barrage, wave, marine currents, thermal gradient and salinity power for electricity production as well as for producing drinking water.

The year also saw research and developmental activities through cost-shared and task-shared activities. Significant progress in the work programme of a collaborative Annex on guidelines for conversion devices and another Annex on integration of ocean energy to electrical grids has been made during the year. A new collaborative initiative through an Annex to address environmental issues associated with ocean energy conversion processes was initiated in this year.

The IEA-OES decided to participate with the IEA Renewable Energy Technology Deployment (RETD) Implementing Agreement on an initiative to accelerate the deployment of offshore energy technologies. The IEA-OES also contributed to two major IEA publications in 2008, published just prior to the G8 meeting in Japan. The Executive Committee (ExCo) has also approved a project and the necessary funding in 2008 for collaboration with the IEA Secretariat for producing a joint Ocean Energy Technology Perspective publication.

As part of our outreach and communication strategy, the IEA-OES participated in the IEA-UN-GTZ workshop on "Sustainable Rural Energisation in Major Emerging Economies" in Paris, and co-sponsored a Global Marine Renewable Energy Conference in New York City in April 2008 and the Second International Conference on Ocean Energy in Brest, France, in October 2008. Various members spoke on the current collaborative activities of the Implementing Agreement at several national and international workshops, symposiums and conferences.

By the end of 2008, more than 25 countries were involved in ocean renewable energy technology development activities. The deployment of multi-unit wave technology in Portugal, utility-scale tidal current technology in the UK, and construction of a 260 MW tidal power plant in Korea are some noteworthy events of the year.

Although continued and new government policies and initiatives from a few countries to enable the commercialisation of ocean energy technologies in 2008 are welcome, the lack of targeted national priorities and policies for ocean energy remains a major barrier for developing reliable technologies to realise the global potential of this renewable energy source to reducing greenhouse gas emissions.

On a personal note, representing Canada at the Executive Committee of the IEA-OES over the past six years has been enjoyable. Serving as the Chair of the Executive Committee over the past two years and the associated interactions with individuals from the IEA Secretariat in Paris and the prospective member countries have been particularly challenging and rewarding. I take this opportunity to thank all the Executive Committee members (current and past), the operating agents and the individuals who participated in the ExCo meetings and workshops as observers and experts for their dedicated efforts and contributions to the IEA-OES during past years. I wish the incoming Chair of the Executive Committee, Dr. John Huckerby from New Zealand, a successful 2009.

Dr. Gouri S. Bhuyan, *P. Eng., Fellow ASME*
Principal Advisor – Alternative Energy
Powertech Labs Inc., Canada

Executive Summary

The IEA Ocean Energy Systems 2008 Annual Report reviews the progress of activities in the Implementing Agreement on Ocean Energy Systems (IEA-OES) under the auspices of the International Energy Agency (IEA) during the year 2008.

The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) in 1974, to implement an international energy programme and act as policy advisor to countries on energy, including renewable energy. Today the IEA has 28 member countries. The IEA provides a framework for 42 international collaborative energy research, development and demonstration projects known as Energy Technology Agreements. These Implementing Agreements were created to encourage collaborative efforts to meet the main challenges of energy policies: ensuring energy security and addressing climate change issues in a cost-effective way.

The IEA Ocean Energy Systems Implementing Agreement (IEA-OES) is a collaborative venture among various member countries and the European Commission. As of December 2008, those members are Portugal, Denmark, United Kingdom, Japan, Ireland, the European Commission, Canada, the United States of America, Belgium, Germany, Norway, Mexico, Spain, Italy, New Zealand and Sweden, ordered by sequence of joining the Agreement.

Chapter 1 of this report gives an overview of the IEA-OES: its membership, the Executive Committee (ExCo) meetings, actual collaborative tasks of the work programme (known as Annexes to the IEA-OES programme), events and activities in which the ExCo participated or collaborated, new initiatives during the year and finally the presentation of the financial status of the IEA-OES as of December 2008.

The outcomes of the three collaborative tasks of the IEA-OES (collection and dissemination of information, guidelines for prototype testing and grid integration) are presented in chapter 2, reported by the respective operating agent of each task.

- Under Annex I, collection and dissemination of information, three activities are outlined: a DVD on ocean energy produced during the year with contributions from the members, the launch of the new IEA-OES website and the new report approved as an IEA-OES publication, *Ocean Energy: Global Technology Developmental Status*.
- Under Annex II, guidelines for prototype testing, task participants started to prepare a report with reference data for wave and tidal stream projects reflecting realistic operating and survival conditions; means to provide comparable estimates of the cost during the development process from conceptual idea to prototype development; and finally considerations on how to measure the output and to present results from projects operating at sea.
- Under Annex III, grid integration, two draft reports were prepared: Report No 3.1.1, *Potential opportunities and differences associated with integration of ocean wave and marine current energy plants, in comparison to wind energy*, and Report No. 3.1.2, *Key features and identification of improvement needs to the existing relevant interconnection guidelines for facilitating integration of ocean energy pilot projects*.

A new task was approved in 2008 by the ExCo, Annex IV – Assessment of Environmental Effects and Monitoring Efforts for Ocean Wave, Tidal, and Current Energy Systems. Its aim, description and schedule are also provided in chapter 2 by the respective operating agent.

Under Chapter 3, six articles written by invited experts provide a broad overview of the technological status for harnessing energy from tides, wave, tidal stream, temperature gradient and salinity gradient for generating electricity and producing drinking water.

Finally, under Chapter 4, a summary on national activities is provided by the IEA-OES member countries and representatives from some other potential member countries focusing on i) ocean energy policy, ii) research and development and iii) technology demonstrations during the year.

Dr. Ana Brito e Melo
Secretary to the Executive Committee
Wave Energy Centre, Portugal

1. Ocean Energy Systems Program

IEA-OES

The International Energy Agency (IEA) provides a framework for more than 40 collaborative programmes, known as Implementing Agreements, in the areas of renewable energy, hydrogen, fossil fuels, fusion power, end use and cross-cutting activities for technology research, development, demonstration and deployment. The Implementing Agreement on Ocean Energy Systems (IEA-OES) is one of ten IEA Implementing Agreements within the renewable energy domain. The IEA-OES was set up in October 2001 and is now under its second 5-year term mandate.

The IEA-OES programmes bring together countries to advance research, development and demonstration of conversion technologies to harness energy from all forms of ocean renewable resources, such as tides, waves, currents, temperature gradient and salinity gradient for electricity generation as well as for other uses, such as, desalination, through international cooperation and information exchange.

Vision of the IEA-OES

To realise, by 2020, the use of cost-competitive, environmentally sound ocean energy on a sustainable basis to provide a significant contribution to meeting future energy demands.

IEA-OES Mission

To facilitate and co-ordinate ocean energy research, development and demonstration through international co-operation and information exchange, leading to the deployment and commercialisation of sustainable, efficient, reliable, cost-competitive and environmentally sound ocean energy technologies.

Strategic Objectives (2007-2011)

1. To actively encourage and support the development of networks of participants involved in research, development and demonstration, prototype testing and deployment, policy development, and deployment, and to facilitate networking opportunities.
2. To become a trusted source of objective information and be effective in disseminating such information to ocean energy stakeholders, policymakers and the public.
3. To promote and facilitate collaborative research, development and demonstration to identify and address barriers to, and opportunities for, the development and deployment of ocean energy technologies.
4. To promote policies and procedures consistent with sustainable development.
5. To promote the harmonisation of standards, methodologies, terminologies and procedures where such harmonisation will facilitate the development of ocean energy.

Membership

After the signature of **Spain, Italy** and **New Zealand** at the beginning of 2008, **Sweden** also became member of the IEA-OES, bringing the number of members to 16. **France** and **Australia** initiated the procedure to formally join the IEA-OES. The IEA-OES Executive Committee officially invited the **Netherlands, India, Chile** and **China** to become members.

Year	Country	Contracting party
2001	Portugal	Instituto Nacional de Engenharia Tecnologia e Inovação (INETI)
2001	Denmark	Ministry of Transport and Energy, Danish Energy Authority
2001	United Kingdom	Department of Energy and Climate Change (DECC)[1]
2002	Japan	Saga University
2002	Ireland	Sustainable Energy Ireland (SEI)
2003	European Commission	Commission of European Communities
2003	Canada	Powertech Labs Inc.
2005	United States of America	United States Department of Energy (DOE)
2006	Belgium	Federal Public Service Economy
2007	Germany	The Government of the Federal Republic of Germany
2007	Norway	The Research Council of Norway
2007	Mexico	The Government of Mexico
2008	Spain	TECNALIA
2008	Italy	Gestore Servizi Elettrici (GSE)
2008	New Zealand	Aotearoa Wave and Tidal Energy Association (AWATEA)
2008	Sweden	Swedish Energy Agency

[1] The Department of Energy and Climate Change (DECC) is designated to replace The Department for Business, Enterprise and Regulatory Reform (BERR)

Table 1.1. Contracting Parties to the IEA-OES (status: Dec. 2008)

Executive Committee Meetings

The work programme within the Implementing Agreement is co-ordinated by an Executive Committee (ExCo), which in turn is typically represented by a government department or its nominee from member countries. Under the IEA-OES, the ExCo develops the strategy to pursue and establishes collaborative work programmes. The ExCo meets twice every year. The 2008 ExCo meetings were held in New York City, USA (April 2008), and in Brest, France (October 2008).

14th ExCo meeting

15-16 April 2008, New York City, USA
This meeting was hosted by the American National Standards Institute (ANSI) in New York City, and it was held at the headquarters of the ANSI, with 24 participants. The alternate member from USA, Mr. Walt Musial, was the local organiser of the meeting.

15th ExCo meeting

13-14 October 2008, Brest, France
This meeting was hosted by IFREMER, the French public institute for marine research, contributing through studies and expert assessments, to knowledge about the ocean and its resources, monitoring of marine and coastal zones and the sustainable development of maritime activities. The meeting was held in Ifremer with 27 participants

14th IEA-OES ExCo meeting group in New York City, at the United Nations

Work Programme

The mechanisms of collaboration have been through the activities of specific tasks (known as Annexes to the work programme). By end of 2008, the work programme of the IEA-OES is comprised by the following three tasks:

Task 1
Review, Exchange and Dissemination of Information on Ocean Energy Systems

Task 2
Development of Recommended Practices for Testing and Evaluating Ocean Energy Systems

Task 3
Integration of Ocean Energy Plants into Distribution and Transmission Electrical Grids

The objective of the Task 1 work programme is to collate, review and facilitate the exchange and dissemination of information on technical, economic, environmental, policy and social aspects related to development, demonstration and deployment of ocean energy technologies. The Task 2 programme was initially designed to develop recommended practices for testing and evaluating wave and tidal current conversion devices in the laboratory. An IEA-OES guideline was produced in 2003. This task has been extended in 2006 to develop guidelines for evaluating prototypes in sea. The Task 3 programme focuses on conducting cooperative research and information exchange related to integration of ocean energy to electrical systems.

In 2008 a fourth task was approved: Task 4 (Annex IV) – Assessment of Environmental Effects and Monitoring Efforts for Ocean Wave, Tidal and Current Energy Systems.

Members of IEA-OES are invited to participate in all of the tasks, but each member is free to limit its participation to those tasks that have a programme of special interest, except for the mandatory Task 1. In Task 1 participants assign specific resources and personnel to carry out the work. Task 2, Task 3 and Task 4 are based on cost-shared and task-shared activities.

Highlights in 2008

The milestones of the 2007 work program can be summarised as follows:

- **Increased membership and spread of the IEA-OES worldwide:** In 2008 four countries joined the IEA-OES: Spain, Italy and New Zealand in beginning of the year, and Sweden in August. Several observing countries attended the executive committee meetings: Brazil, South Africa, India, Chile and Russia. The French government announced at ICOE 2008 conference in Brest that France would be joining the IEA-OES. The Australian government has also informed the IEA secretariat that it would join the IEA-OES.

- **Launch of a new task:** Recognising the need for information on environment effects related to ocean wave, tidal and current energy technologies, discussed at the workshop in Messina, Italy, in 2007, a new collaborative task on assessment of environmental effects and monitoring efforts for ocean wave, tidal and current energy systems was approved by the Executive Committee in 2008.

- **Renew of the website:** The IEA-OES website (www.iea-oceans.org) was renewed and launched on June 2008.

- **New publications:** Two publications were produced: a *Wave Data Catalogue*, prepared by INETI/LNEG; and the report, *Ocean Energy: Global Technology Developmental Status*, prepared by Powertech Labs Inc.

- **Production of a DVD on ocean energy**: The first IEA-OES DVD on ocean energy was produced during the year including interviews with relevant experts, the views of some of the IEA-OES members on ocean energy perspectives and examples of the technology, covering tidal energy, wave energy and marine current energy, OTEC and salinity.

Participation in IEA events

The IEA-OES continued to strengthen its dissemination activities through presentations in events, conferences and symposiums relevant to ocean energy. The IEA-OES has been further participating in the Networks of Expertise in Energy Technology (NEET) events, as described below.

IEA Workshop on Energy Technology Roadmaps

IEA, Paris, France, 15-16 May 2008

The IEA organised a workshop to develop technology roadmaps as a mean to identify where international collaboration can accelerate energy technology development. The aim of this workshop was to collect and assess existing roadmaps and to discuss what is needed to develop effective energy technology roadmaps for international collaboration. Technology roadmaps can help industry, academic and research groups, civil society and governments to identify and prioritise strategic research, development and investment needed to achieve technology development goals. The IEA-OES discussed the need for developing an international roadmap for ocean energy technologies in the April ExCo meeting, reinforcing the relevance of IEA-OES representation in the IEA Workshop on Energy Technology Roadmaps. Mr. Henry Jeffreys, from the Edinburgh University (UK), joint author of the Roadmap for marine renewable energy developed in UK, attended the IEA Workshop on behalf of the IEA-OES.

Sustainable Rural Energisation in Major Emerging Economies

IEA, Paris, France, 28-29 May 2008

The objective of this workshop was to identify whether there is concrete interest from major developing economies in working more closely on the issue of rural energisation. The core question that was addressed is whether such collaboration could be facilitated and enhanced through the Implementing Agreements. Presentations and debates were focused on collaborative opportunities with other countries and the IEA Technology Network.

Country representatives from Brazil, China, India, Mexico and South Africa presented their local objectives, policies, constraints and perspectives, as well as how they seek to overcome the major underlying difficulties in sustainably energising their rural areas. Presentations also indicated where they see opportunities for collaboration with the IEA Implementing Agreements. Representatives of the Implementing Agreements participating in the workshop introduced the current activities in their IAs and future prospects related to "sustainable rural energisation". The Chair made a presentation with relevant activities in which some of the members were already involved. Prof. Fiorentino, the alternate member from Italy also attended the workshop. The ExCo agreed to review and discuss the need for developing a work programme on rural energisation.

Sustainable Rural Energisation in Major Emerging Economies, IEA, Paris, 28-29 May 2008

NEET Workshop on Energy Technology Collaboration

Moscow, Russia, 30 September – 1 October 2008

This workshop was one of a series of Networks of Expertise in Energy Technology (NEET) events stimulated by the request of the G8 and the IEA Governing Board with the aim of facilitating co-operation with the international business community and developing countries. During this workshop, IEA Working Parties and Implementing Agreements had the opportunity to present and discuss with Russian stakeholders from government, industry, research and academia what energy technology collaboration can achieve. The IEA-OES was represented in this workshop by the IEA-OES Vice-chair, Mr. Jochen Bard, who made a presentation on behalf of the IEA-OES in the session "Ocean Energy and Hydropower." Information of this workshop is available at www.pt21.ru.

Co-sponsored Symposiums

The IEA-OES co-sponsored two international conferences during 2008.

Global Marine Renewable Energy Conference

New York City, USA, 17-18 April 2008

The Global Marine Renewable Energy Conference, "Achieving renewable goals with ocean energy resources", was held at New York City, USA, in April 2008, co-sponsored by the IEA-OES and the USA alternate member of the IEA-OES, Mr. Walt Musial, of the National Renewable Energy Laboratory, who was the conference chair. In this event, IEA-OES members shared their experiences with policies, incentives and subsidies to promote the demonstration and deployment of marine renewable energy technologies; some members presented their experiences in assessing the technology challenges and lessons learned from early demonstration efforts in marine renewables. Others discussed how to measure and evaluate environmental effects in marine renewable energy projects.

Second International Conference on Ocean Energy (ICOE 2008)

Brest, France, 15-17 October 2008

The IEA-OES co-sponsored the second International Conference on Ocean Energy (ICOE 2008), "From Innovation to Industry", that was held from 15 to 17 October in Brest, France, in the frame of the Sixth International Marine Science and Technology week (SeaTechWeek), a multidisciplinary forum. This conference covered waves, currents (tidal or ocean currents), tide (tidal energy), ocean thermal energy conversion (OTEC), salinity gradient, offshore wind and biomass. The IEA-OES prepared a paper entitled "International Collaboration and Role of IEA-OES" by G. Bhuyan, J. Bard, J. Huckerby, T. Pontes and A. Brito-Melo, to be published in the conference proceedings and presented by the IEA-OES Chair.

ICOE 2008, Brest, France, co-sponsored by IEA-OES

Collaborative activities with the IEA

IEA G8 Project Integration of Renewables into Electricity Grids

The operating agent of Task 3 collaborated with the IEA project team on behalf of IEA-OES and provided some inputs relevant to ocean energy. The IEA published a paper entitled *Empowering Variable Renewables: Options for Flexible Electricity Systems* prior to the G8 meeting in Japan in 2008. The paper focuses on the issue of flexibility of power systems, on measures to increase the flexibility of network and market operation, to enable a greater share of variable renewable electricity.

IEA Publication Energy Technology Perspectives – Strategies and Scenarios for 2030 and 2050

The Chair provided comments and held discussions with the IEA secretariat related to ocean energy for a section of the IEA publication. The IEA book was published just prior to the 2008 G8 meeting in Japan.

Collaboration with the IEA RETD

The IEA Renewable Energy Technology Deployment Implementing Agreement (IEA-RETD) hosted a one-day workshop, *Climate Change, Security of Supply and Soaring Energy Prices – The Role of Renewables in Global Energy Models*, on 22 October 2008, in Copenhagen, Denmark, in which 40 experts from governments, IEA implementing agreements, science and the private sector participated. The Danish alternate member of the IEA-OES attended the workshop.

New Initiatives of the IEA-OES

New Annex to the IEA-OES Work Programme

In 2007, the ExCo raised environmental issues related to ocean energy systems by organising a workshop, *Potential Environmental Impacts and Ocean Energy Devices* (Messina, Italy, October 2007). In 2008, the ExCo decided to start preparing a work programme proposal for a new Annex under this topic, and at its October 2008 meeting, approved a proposal from the USA member, *Annex IV – Assessment of Environmental Effects and Monitoring Efforts for Ocean Wave, Tidal, and Current Energy Systems*.

IEA Book, *Ocean Energy: Status, Prospects and Strategies*

The IEA-OES in 2008 approved a new collaborative initiative to produce an IEA publication on ocean energy technology. The ExCo has agreed to co-fund the initiative, initially proposed by the IEA Secretariat. The aim of this book is to ensure ocean energy has a more integral role in the portfolio analysis of the IEA, with particular focus on the IEA publication *Energy Technology Perspectives*, 2010 edition. The proposed project will result in a book that is intended to fulfil the following objectives:

- To provide a single, detailed, authoritative reference for the status quo of ocean energy development and its potential.
- To directly influence and interact with modelling and roadmapping activities at international and national levels, including: IEA Secretariat modelling activities, specifically the proposed 2010 Energy Technology Perspectives publication; Intergovernmental Committee on Climate Change (IPCC) work relating to renewable energy impacts on climate change; European Commission-funded studies relating to ocean energy systems; and other national initiatives.

Global Ocean Energy Roadmapping

Further discussions were held during the year by various representatives on the need for developing a Global Ocean Energy Roadmap. Based on feedback and interest from some members, the IEA-OES is moving ahead with developing a relevant work programme that could be considered for a new collaborative task.

Organisation of Site Visit to the IEA-OES Group

The members of the ExCo visited the Verdant Power's Roosevelt Island Tidal Energy (RITE) Project being operated in New York City's East River. This project was initiated in 2002 and is progressing from an initial demonstration array of six turbines to a full field of turbines. This visit was organised by the USA Alternate, Mr. Walt Musial, for occasion of the 14th ExCo meeting in New York City and all participants in the meeting had the opportunity to visit the project monitoring room.

Financial Status of the IEA-OES

The income for the operation of the IEA-OES is generated through the annual membership fees. Since 2007, the IEA-OES common fund is managed by the Wave Energy Centre in Portugal, the Secretariat for the IEA-OES. The IEA-OES common fund was audited by Moore Stephens auditing company in Portugal in January 2009, and provides net assets of EUR 116 325 for the IEA-OES for the operation ending 2008. Details on the income and liabilities are summarised below.

IEA – OES Common Fund
Balance Sheet (in Euros) as of December 31, 2008

Current assets	
Accounts receivable	10000
Bank account	133659
Total assets	**143659**
Current liabilities	
Accounts payable	
Expenditures from previous year	-15500
Expenditures 2008	-5833
Other	-6000
Total liabilities	**-27333**
Net assets	**116325**

2. Task Status Reports

Review, Exchange and Dissemination of Information on Ocean Energy Systems (Task 1 or Annex I)

Operating Agent: Dr. Teresa Pontes – Instituto Nacional de Engenharia e Tecnologia e Inovação (INETI/LNEG), Portugal

Objectives

The objective of this task is to collate, review and facilitate the exchange and dissemination of information on the technical, economic, environmental and social aspects of ocean energy systems. This available knowledge should facilitate further development and adoption of cost-effective ocean energy systems. In addition, the results of this task will facilitate identification of further Annexes, as well as continuing to promote information exchange.

Participating Countries and Organisations

This Annex is a mandatory Annex of the IEA-OES.

Achievements and Progress in 2008

Production of an Informational DVD on Ocean Energy

A DVD on ocean energy was prepared during 2008 with the objective to promote ocean energy as a viable energy resource, and to educate decision makers and the public about what ocean energy is and how it can contribute to sustainable energy production. The DVD will be distributed in early 2009 and be available for download in the IEA-OES website.

Newsletter

The IEA-OES newsletter is prepared every six months with information provided by the members on ocean energy activities, political initiatives and device demonstrations worldwide. Examples of those articles in the 2008 issues are:

- NEREIDA MOWC, a demonstration project involving the integration of Oscillating Water Column (OWC) systems in the new breakwater at the harbour in Mutriku on the Basque coast in Spain (Issue 10, April 2008).
- The plans from Statkraft, a North European electricity generator, to build an osmotic power plant prototype in Norway to further verify the osmotic power system (Issue 10, April 2008).
- Marine energy activities in New Zealand including the deployment of an experimental wave energy device, WET-NZ (Issue 11, October 2008).
- SeaGen tidal marine currents project, installed in Northern Ireland during 2008 (Issue 11, October 2008).

New IEA-OES Website

The website www.iea-oceans.org is the primary source of information about the activities of the IEA-OES. It provides easy access to its major IEA-OES documents, including Annex descriptions, reports, newsletters and membership information, as well as notification of upcoming events. The website is maintained by the Wave Energy Centre in Portugal.

IEA-OES On-line Reference Library

The On-line Reference Library continued to be populated with references from conferences and also published reports provided by the ExCo members. The references are organised into 14 main topics. Most relevant publications in journals started to be included. The references can be sorted by chronological order, alphabetical order of titles, authors and types. From this Library the UK SuperGen Database can be directly accessed.

IEA-OES Publication T0103 Wave Data Catalogue for Resource Assessment

The objective of the Wave Data Catalogue for Resource Assessment is to provide the basic information required for wave energy resource assessment, including a listing of published atlases and databases and wave data sets available in IEA-OES member countries.

It starts with the description of ocean waves and the associated energy and power, which is followed by the description of the various sources of wave information. These include in situ and remote sensed data, and result of numerical wind-wave models. In situ data are obtained from various measuring devices that are selected according to local condition namely water depth; remote sensed data are obtained radars on board of satellites (altimeter and Synthetic Aperture Radar) and also land-based radars. Results of numerical wind-wave models have good accuracy providing actually a majority of wave information. They are run at global, regional and local scales at various centres and institutes worldwide. Information on most important models and their available results is reviewed.

The Catalogue includes the references of most relevant wave and wave energy atlases and databases. A country-by-country summary of the available wave datasets based on information provided by the IEA-OES is presented.

IEA-OES Publication T0104 Ocean Energy: Global Technology Developmental Status

Following the evaluation of the development of ocean energy technologies presented in the IEA-OES 2006 report *Review and Analysis of Ocean Energy Systems, Development and Supporting Policies*, additional evaluation of the technologies and their development status was carried out in 2007 by Powertech Labs. The report *Ocean Energy: Global Technology Developmental Status*, approved in 2008 as an IEA-OES publication, analyses the current development status of tidal barrages, tidal current, ocean wave, OTEC and salinity gradient technologies. Further, the report describes initiatives on ocean energy undertaken by various entities and discusses various projects in operation with emphasis on several specific systems being developed.

Other Publications on Behalf of the IEA-OES

- Bhuyan, G., "Harnessing the Power of Oceans", *IEA OPEN Energy Technology Bulletin*, Issue No. 52, July 2008.
- G. Bhuyan, J. Bard, J. Huckerby, T. Pontes and A. Brito-Melo, "International Collaboration and Role of IEA-OES", *Proceedings of the 2nd International Conference on Ocean Energy (ICOE 2008)*, Brest, France, 15-17 October 2008.

Plan for 2009

In 2009 Annex I will continue to collect exchange and disseminate information on Ocean Energy through the various means that have been set up namely the IEA-OES site (www.iea-oceans.org), the biannual Newsletters that provide contributions on achievements, plans and policies developed by the Member-Countries, and participation of ExCo members in conferences and meetings. A major outcome will be the book Ocean Energy: Status, Prospects and Strategies a joint publication of the IEA-OES and the IEA Secretariat.

Development of Recommended Practices for Testing and Evaluating Ocean Energy Systems (Task 2 or Annex II)

Operating Agent: Dr. Kim Nielsen – RAMBØLL, Denmark

Objectives

The objective of this task is to develop recommended practices for testing and evaluating ocean energy systems and, this task was extended in 2006 to address prototypes. The overall objective of the extended work programme is to provide the necessary basis in order to present the performance of different ocean energy systems in a comparable format.

WP 1 Generic and Specific Wave and Tidal Current Reference Data

Task 2.1.1: Generic and site-specific wave resource data.
Task leader: Teresa Pontes, INETI/LNEG, Portugal [1]

Task 2.1.2: Generic and site-specific tidal current resource data.
Task leader: Andrew Cornett, National Research Council Canada, Canada [2]

WP 2: Development and Evaluation Protocols for Ocean Energy

Task 2.2.1 Development and evaluation protocols for wave energy
Task leader: Brian Holmes, UCC, Ireland [3]

Task 2.2.2 Tidal development protocol
Task leader: Howard Rudd, AEA, UK [4]

WP 3 Guidelines for Open Sea Testing and Evaluation of Ocean Energy Systems

Task 2.3.1 Data monitoring and acquisition
Task leader: Brian Holmes, UCC, Ireland [5]

Task 2.3.2a Assessment of the performance of wave energy systems
Task leader: Howard Rudd, AEA, UK [6]

Task 2.3.2b Assessment of the performance of tidal energy systems:
Task leader: Howard Rudd, AEA, UK [7]

Task 2.3.3 Guidelines on design, safety and installation procedures, wave and tidal
Task leader: Howard Rudd, AEA, UK [8]

Participants

Countries	Organisation	Individual
Belgium	Federal Public Service Economy	Julien DeRouck and Pieter Mathys
Canada	National Research Council Canada	Andrew Cornett
Denmark	The Ministry of Transport and Energy, Danish Energy Authority	Kim Nielsen
Ireland	Sustainable Energy Ireland (SEI)	Brian Holmes (University College Cork)
Mexico	The Government of Mexico	Gerardo Hiriart
Norway	The Research Council of Norway	Petter Hersleth
Portugal	INETI/LNEG	Teresa Pontes
Spain	TECNALIA	Jose Luis Villate
UK	Department of Energy and Climate Change (DECC)	Howard Rudd (AEA)
USA	United States Department of Energy (DOE)	Alejandro Moreno and Walt Musial

Achievements and Progress in 2008

All major contributions from members were received in 2008 and are in the process of being compiled into a main report. This report will include from the first work package reference data for wave and tidal stream projects reflecting realistic operating and survival conditions. From the second work package, a development structure is presented and a means to provide comparable estimates of costs during the development process from conceptual idea to prototype development. The last work package deals with how to measure the output and how best to present and evaluate the results from projects that have reached the prototype stage and are operating at sea. The last work pack builds on the work published in May 2007 by BERR, two monitoring protocols to enable devices deployed under the Wave and Tidal-stream Energy Demonstration Scheme to report their performance in a consistent, transparent, unambiguous and meaningful way. Further, the IEC 114 standardisation group on ocean energy has interaction with the IEA-OES Annex II group.

During 2008, the reports for the Annex have in large part been completed as shown on the list of references below. Two of the references are still not completed; however, it is expected that all reports will be available by the end of 2009.

A progress meeting was held in Brest in October 2008 and each task leader made a presentation on his or hers respective task. It was agreed that effort should be made to compile the individual contributions into a main document and to include the task reports in appendices.

References:

Work package (WP) 1:

[1] *Under preparation*

[2] *Guidance for Assessing Tidal Current Energy Resources*, Report CHC-TR-058 (Draft), October 2008, Andrew Cornett, Canadian Hydraulics Centre, National Research Council Canada

Work package (WP) 2:

[3] *Tidal-Current Energy Device Development and Evaluation Protocol*, URN: 08/1317
Contractor: University of Southampton.

[4] *Ocean Energy: Development and Evaluation Protocol*, HMRC, September 2003

Work package(WP) 3:

[5] *Under preparation*

[6] *Preliminary Wave Energy Device Performance Protocol* Version 1.3 – March 2007, URN 07/807, Prepared by Heriot-Watt University and the University of Edinburgh

[7] *Preliminary Tidal Current Energy: Device Performance Protocol,* Version 1.3 – February 2007, URN 07/838, Prepared by the University of Edinburgh

[8] *Assessment of Performance for Tidal Energy Conversion Systems*, Rep, Urn 08/1154, Contractor: European Marine Energy Centre Ltd

[9] *Design Basis Guidelines for Marine Energy Converters* (Draft), European Marine Energy Centre Ltd

Plan for 2009

Based on the response to the Annex II draft report at the next ExCo meeting in Spain (March 2009), a final version will be compiled during 2009.

Integration of Ocean Energy Plants into Distribution and Transmission Electrical Grids (Task 3 or Annex III)

Operating Agent: Dr. Gouri S. Bhuyan – Powertech Labs Inc., Canada

Objectives

The overall aim of this Annex is to provide a forum for information exchange related to integration of ocean energy into electrical systems, considering generation, transmission and distribution. The scope encompasses relevant co-operative task-shared research activities and information gathering among the participants.

WP 1 (Subtask 3.1) – Identify potential differences and opportunities associated with the longer-term large-scale integration of wave and tidal current energy plants in comparison with wind energy, and identify improvements to the existing interconnection guidelines to facilitate early stage pilot wave and tidal projects.

WP 2 (Subtask 3.2) – Develop specification for characterisation of wave and tidal current conversion devices, and create a database for some generic classes of conversion process. The scope includes reviewing best practices characterising different generation technologies.

WP 3 (Subtask 3.3) – Modelling case studies involving integration of wave and tidal current plants to an electrical system. The scope includes compilation of existing and new studies involving transmission and/or distribution network modeling for determining deployment targets for ocean energy and/or network capacity limits, as well as potential ocean energy production in some target geographical areas.

The work programme also includes "Coordination" activities with other relevant IEA initiatives, and the operating agent has been coordinating the activities of this Annex with others.

Participating Countries and Organisations

The ExCo member countries that are participating in the work programme of the Annex are Canada, Ireland, United Kingdom, Spain and New Zealand. Other countries, such as Germany and Denmark, may join this Annex in 2009.

Powertech Labs of Canada is the leader for WP 1 with contributions from the Department of Energy and Climate Change (DECC), UK (through AEA Technology), Sustainable Energy Ireland (SEI), Ireland (through the Hydraulic Maritime Research Centre – HMRC), TECNALIA, Spain, Aotearoa Wave and Tidal Energy Association (AWATEA), New Zealand, and others.

HMRC of Ireland is the Leader for the WP 2. Contributions to this WP are expected from AEA Technology, Powertech Labs, TECNALIA, AWATEA and others.

As of December 2008, leader for the WP 3 has not been confirmed. Potential contributions to this WP are expected from Spain, Ireland, UK, Canada, New Zealand and others.

Achievements and Progress in 2008

The activities of WP 1 (Subtask 3.1) were carried out in 2008. Based on the completion of the WP activities, following two draft reports were prepared by the WP leader:

- **Report No 3.1.1**, *Potential opportunities and differences associated with integration of ocean wave and marine current energy plants, in comparison to wind energy*. This document presents characteristics of some wave and tidal current energy conversion processes and identifies areas where the ocean energy technologies bear unique advantages in comparison to wind energy technologies. The report also discusses how the experience gained from the wind energy industry could be used to mitigate any future grid integration challenges associated with a large-scale implementation of ocean energy technologies.
- **Report No. 3.1.2**, *Key features and identification of improvement needs to the existing relevant interconnection guidelines for facilitating integration of ocean energy pilot projects*. This report presents a review of some relevant interconnection guidelines and identifies key components of a generic guideline. Considering the early deployment stage of ocean energy technologies, the report discusses how a flexible interconnection guideline could be developed to accelerate the deployment.

The reports have been finalised based on the comments received from the participating organisations.

A progress meeting of the Annex was held in Brest on October 2008 to discuss the WP 1 (Subtask 3.1) reports, and the scope and plan of action for the WP 2 (Subtask 3.2) and 3 (Subtask 3.3) activities. The WP leader at the progress meeting outlined a detailed plan of action for carrying out Subtask 3.2.

Plan for 2009

During 2009, in addition to finalising the above two WP 1 reports, activities for WP 2 (Subtask 3.2) will be carried out through the following specific stages:

- Reviewing grid companies requirements and best practices for characterising different generation technologies
- Development of a specification for characterising a generic class of wave and tidal current conversion processes
- Creating a database for device-type dynamic models

Further discussions with the Annex's current participants and other prospective participants will be held to identify an appropriate organisation that will be able to lead the activities of WP 3 (Subtask 3.3). Depending upon the outcome of these discussions, and the timing, appropriate work activities for the WP in 2009 will be determined.

The next face-to-face annual meeting of the Annex members will be held in September 2009.

Assessment of Environmental Effects and Monitoring Efforts for Ocean Wave, Tidal and Current Energy Systems (Task 4 or Annex IV)

Operating Agent: Mr. Alejandro Moreno – United States Department of Energy (DOE), USA.

Background

A draft proposal for a new Annex on assessment of environmental impacts was presented at the October ExCo meeting. This Annex proposal responds to a need for information on the environmental effects related to ocean wave, tidal and current energy technologies described in the report from the IEA-OES workshop (Messina, Italy, October 2007. See National Renewable Energy Laboratory (USA) and Natural Resources Canada (Canada), *Potential Environmental Impacts Of Ocean Energy Devices: Meeting Summary Report*, 18 October 2007). The Messina report highlighted a need to combine the lessons of related studies and to share robust, reliable monitoring methods that detect change and that are adaptable to the unexpected. The Messina report concludes with a table listing and prioritising environmental issues related to the technologies.

The Annex IV effort will start where the Messina report left off, listing and identifying potentially critical environmental issues associated with the new technologies, as identified in recent syntheses of the available information on the new technologies. The syntheses employed will include one being prepared by the United States Department of Energy (USDOE) using data from around the world and due out to the US Congress in January 2009; the April 2008 Fundy Tidal Energy Strategic Environmental Assessment by the Nova Scotia, Canada, Department of Energy; the July 2007 Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf by the US Department of the Interior's Minerals Management Service; and the March 2007 Scottish Marine Renewables Strategic Environmental Assessment by the Scottish Executive, among others.

This report addresses ocean wave, tidal and current energy development and does not address offshore wind power or ocean thermal energy conversion (OTEC). Ocean wave, tidal and current technologies are the focus of a great deal of activity at the moment and have a much shorter history of study than that of OTEC. However, to the extent that information from the wind power or OTEC industry can be applied to these other technologies, it will be used in analysis.

Objectives

Annex IV will increase our understanding of the environmental effects of ocean wave, tidal and current energy development on the marine environment. Depending on the extent of information available, examples of environmental impacts for potential consideration may include impacts to benthic organisms, fish, marine mammals, birds, sediment transport and coastal processes, multiple uses, visual impacts, social impacts and economics, among others. Before analysis begins, Annex members will determine which impacts should be included to ensure that efforts are focused on priority needs.

The Annex will facilitate efficient government oversight of the development of ocean energy systems by expanding our baseline knowledge of environmental effects and monitoring methods. One of the primary goals of the Annex is to ensure that existing information and data on environmental monitoring (and, to the extent possible, practices for environmental mitigation) are more widely accessible to those in the industry; national, state and regional governments; and the public. The Annex will facilitate knowledge and information transfer. The database and the final report will be made publicly available. Annex participants will compile and assess information from existing and proposed environmental monitoring studies. Monitoring protocols and results will be documented in a prescribed report format and lessons learned regarding monitoring methods will be identified. If monitoring has revealed viable practices for mitigating environmental effects, those practices will be reported.

The Annex will culminate in an accessible and searchable database, an experts workshop and a comprehensive summary report that will be published by the IEA-OES. The report will present all relevant information gathered, provide critical analysis on monitoring efforts and mitigation and provide guidance to international ocean energy stakeholders, including policymakers, developers, regulators, agencies, academic institutions and research organisations. Greater understanding of the environmental effects and monitoring methods related to ocean energy will foster public acceptance and help to advance ocean energy technology.

Work programme

Year 1 (2009)
Identify potential environmental effects of ocean wave, tidal, and current energy systems; compile existing monitoring information and identify high priority information gaps; design and develop database; and begin to enter data.

Specific tasks include:
a) Identify and review valuable existing syntheses addressing ocean wave, tidal or current energy systems.
b) Based on existing syntheses, assemble a master list of potential environmental effects, related monitoring methods, and (if possible) mitigation strategies.
c) Design and develop the database and input data on environmental effects, monitoring methods, and (if possible) mitigation strategies.
d) Identify and prioritise crucial information gaps related to monitoring methods and environmental impacts, and select higher priority gaps for further evaluation using analogous technologies.

Year 2 (2010)
Develop a standard data format; identify, select and compile into the database case study information; and research analogous technologies (analogues) for additional information.

In an effort to better understand the current state of ocean energy systems and associated environmental challenges, existing projects conducting environmental monitoring studies will be identified, selected and reviewed by participating countries. These environmental case study reports will detail the specific methods and findings of each project with particular emphasis on identifying potential environmental impacts, environmental monitoring methodologies and mitigation efforts. Cooperation from project developers may be a critical component in this task in order to obtain the information necessary to carry out the proper analysis. The Annex participants will work closely with identified project managers or developers and only request information needed to complete the case studies analysis.

Specific tasks include:
e) Develop a standard format for reporting case study information, which may include, for example, the following fields: type and location of project, device monitored, generating capacity, power source, water depth, special environmental issue of concern, planned duration of monitoring efforts, frequency and timing of monitoring, measurement strategy and technology, estimated project cost, monitoring cost and funding source, relevant findings, and strengths and weaknesses of monitoring approaches and mitigation efforts.
f) Identify projects where ocean wave, tidal or current energy devices are operational and for which environmental monitoring has been or is being undertaken or is planned. Select case studies to be reviewed.
g) Compile and submit case study reports to operating agent.
h) For priority information gaps, participating nations select analogue monitoring and mitigation methods that can be used to help evaluate the environmental effects of ocean wave, tidal and current energy systems (e.g., from wind, aquaculture, ocean thermal energy technology, electric or telecommunications subsea cables, etc.).
i) Enter case study and analogue information into the database and distribute for review by all Annex participants.

Year 3 (2011)
Final analysis of all information and case studies; completion of preliminary, draft and final reports; experts workshop; distribution of final report and database on website.

The Annex IV report will compile all information and analysis from Years 1-3. It will highlight potential environmental effects, describe case studies, identify monitoring and mitigation strategies and discuss lessons learned. The final Annex report will be completed at the end of Year 3. Comments from Annex participants and workshop participants will be incorporated.

Specific tasks include:
j) Analyze the synthesis data, case study data, and analogue information and prepare a preliminary report for initial review including a summary of the database information and any lessons learned and best practices for monitoring and mitigating environmental effects of ocean wave, current and tidal energy devices.
k) Solicit comments on the preliminary report and hold an experts workshop (including participating nations and other experts) to discuss the preliminary findings.
l) Incorporate workshop and written comments into a draft report and distribute the draft report for review by participating nations.

m) Finalise Annex IV Report, including characterisation of the environmental effects of ocean wave, tidal and current systems; identification of successful monitoring methods and mitigation strategies; and description of any lessons learned and best practices (where possible).

n) Post final report and database to the website, and link the final Annex IV database to other ocean energy databases.

Plan for 2009

This Annex shall enter into force upon its members on April 2009 and shall remain in force for a period of three years. The Annex participants will refine and finalise the time schedule before the Annex commences. An initial interest meeting will be held via teleconference or web conference in January 2009 to inform all IEA-OES members and to determine which members will commit to participation. The final schedule will include completion dates for all tasks, regular update meetings among Annex participants (many by video, web or teleconference) and the experts workshop.

3. Invited Articles on Global Status and Perspectives of Ocean Energy Technologies

As part of a new initiative, the ExCo has invited some experts in their technical fields to describe the status of marine energy technologies. Under this section the following articles written by invited experts, provide a broad overview of the technological status for harnessing ocean renewable energy for electricity generation as well as for producing drinking water:

Tidal Range Technologies
Gary Shanahan, Department of Energy and Climate Change, UK

The Development of Wave Energy Utilisation
António F.de O. Falcão, IDMEC, Instituto Superior Técnico, Technical University of Lisbon, Portugal

The Status of Tidal Stream Energy Conversion
A S Bahaj, The University of Southampton, School of Civil Engineering and the Environment, UK

Ocean Thermal Energy Conversion (OTEC) and Derivative Technologies: Status of Development and Prospects
Gérard C. Nihous, Hawaii Natural Energy Institute, University of Hawaii, USA

Status of Technologies for Harnessing Salinity Power and the Current Osmotic Power Activities
Øystein S. Skråmestø and Stein Erik Skilhagen, Statkraft AS, Norway

Utilisation of Ocean Energy for Producing Drinking Water
Purnima Jalihal and S Kathiroli, National Institute of Ocean Technology, Chennai, India

The following invited summary papers represent the views of the authors. The IEA-OES does not necessarily endorse or support the views expressed in the papers.

Tidal Range Technologies

Gary Shanahan
Deputy Director, Severn Tidal Power, Department of Energy and Climate Change, UK
Gary.Shanahan@decc.gsi.gov.uk

There are a number of technologies that can be used to generate power from the tidal range – the difference between high and low tides – of an estuary, bay or river. When the water level outside the impoundment changes relative to the water level inside, the head created enables the production of power from turbines.

The most well understood technology is a tidal barrage in which a barrage spans the estuary, bay or river, which can then be considered in a similar way to a hydroelectric dam. Other technologies that are being considered for exploitation of energy from a tidal range are tidal lagoons, tidal fences and tidal reefs.

Tidal Barrage

A barrage consists of a number of large concrete caissons built from one side of the water to the other, together with some form of embankment where the barrage is connected to land. The barrage contains turbines (usually in the deepest water), sluice gates and ship locks to facilitate navigation.

The reservoir (tidal basin) is filled during the rising tide through the sluice gates (and potentially also through the turbine orifices). During ebb tide, when the water level on the seaward side of the barrage is low enough, the water behind the barrage is released back to the seaward side through the turbines, generating electricity – ebb generation. So a barrage will maximise its energy in locations with a large basin area and maximal difference between high and low tide. The power generated is proportionate to the square of the tidal range and also to the area of the reservoir. There is the possibility of generating electricity on the incoming tide – flood generation – but studies have shown that this is unlikely to lead to significantly greater generation overall and/or may increase the costs or operational risks. It also needs to be considered whether the value of the energy might be significantly increased by using both ebb and flood generation as opposed to ebb only generation. Pumping or additional basins can also be used to optimise the amount and timing of the en-



La Rance (Courtesy of EdF)

ergy output, particularly if the geography of the tidal power project permits.

Barrage systems have relatively high civil infrastructure costs associated with what is in effect the placing of a dam across estuarine systems, and also need to take into account the environmental impacts associated with changing a large ecosystem.

The basic concept of hydroelectric dams is well understood and a barrage is the application of mature and commercially available technology. A 240 MW tidal barrage (22 km^2 reservoir) has been successfully operated at La Rance, on the northern coast of Brittany, France, since it was first commissioned in 1966 after six years of construction using coffer dams. The 24 bulb turbines, each rated 10 MW, have a diameter of 5.3 m and are capable of operating on both ebb and flood tides and of pumping. The power station has generated around 550 GWh a year – enough for a large town of 250 000 households – with high availability in over 40 years of operation. The La Rance barrage has six sluice gates and a lifting road bridge over a lock.

The other operational barrage of any real scale is the Annapolis Royal Tidal plant, which has operated in Canada's Bay of Fundy since 1984 and uses a single 18 MW Stratflo turbine of 7.6 m. The Stratflo turbines are more compact than the bulb turbine for a similar output (rim driven generator) but are only designed for one way (ebb) generation.

A number of other smaller tidal barrages have operated worldwide – including China – where seven tidal plants have a total capacity of over 5 MW, with the largest being the 3.2 MW Jiangxia plant currently using five bulb turbines (with an additional 700 kW Stratflo turbine scheduled), and Russia, where a 400 kW tidal power plant has operated since the early 1960s, intermittently, at KisloGubskaya. The plant was rebuilt in 2004 to house a new experimental floating 1.5 MW orthogonal turbine with a 5 m diameter.
www.sevmash.ru/?id=3748&lg=en

Barrages Under Construction

A 260 MW tidal power plant is currently under construction at Sihwa in South Korea and is expected to commission in 2010. The plant has been installed in an existing dam and will incorporate 10 bulb turbines, each rated 26 MW, with a runner diameter of 7.5 m. It will have an estimated output similar to that of La Rance of around 550 GWh. While relatively small compared to the capacity of the largest hydroelectric dams (10 to 20 GW) this would be the largest tidal facility in the world in terms of installed capacity. However, South Korea has also announced plans for other larger tidal barrages, with, for example, a 520 MW barrage planned for Garolim Bay awaiting planning approval.
www.westernpower.co.kr/english/business/sub04_01.asp

There are a number of other countries that have reported potential for new tidal range projects such as the USA, India, Mexico and Canada. Work in the UK is discussed in more detail below.

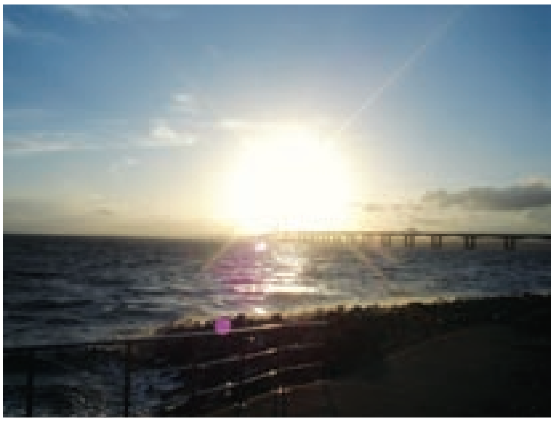
Tidal Lagoons

Tidal lagoons are free-standing structures built offshore or in a semi-circular arrangement connected to the shoreline at each end. Unlike barrages, they would not fully cross an estuary or river. They operate on similar principles to barrages in that they exploit the difference in tidal height to generate electricity using low head hydro turbines. They can also operate in both ebb and flood generation modes. A variety of materials have been proposed from which to construct tidal lagoons ranging from rock-filled embankments to gravity concrete walls and geotextiles.

Further study is required to show whether, on balance, lagoons have less impact on the environment, shipping and other activity as is claimed. There are no operational tidal lagoons at the moment, although a number of projects have been proposed at a variety of scales, particularly in the UK, Mexico and China.
www.tidalelectric.com/Projects.htm

Severn Tidal Power Feasibility Study

www.decc.gov.uk/severntidalpower



Severn Estuary

The Severn Estuary's 14 m (45 foot) tidal range represents a phenomenal source of indigenous, predictable (though intermittent), low-carbon energy. In the 2006 Energy Review the UK government asked the Sustainable Development Commission to investigate tidal power opportunities across the UK. The Commission also considered other UK estuaries as well as the Severn. Their October 2007 report, "*Turning the Tide, Tidal Power in the UK,* concluded, with conditions, that there is a strong case for a sustainable Severn Barrage, and also potential for barrages in other locations with smaller natural resources (such as the Mersey, Wyre and Thames).

(See the report at www.sd-commission.org.uk/publications/downloads/Tidal_Power_in_the_UK_Oct07.pdf)

In response to the SDC conclusions, the UK government launched a two-year feasibility study to investigate whether it could support a Severn tidal power scheme and, if so, on what terms. The study is expected to conclude in 2010 and is considering the costs, benefits and impact of the generation of tidal power in the Severn Estuary.

Ten proposals to generate electricity from the Severn Estuary came forward from a public call for proposals in May 2008 and a strategic review of existing options used in the Sustainable Development Commission's and previous reports. Proposals are at a variety of scales (from 0.625 GW to 14.8 GW) and include barrages, land-connected and offshore lagoons, a tidal fence (a continuous line of underwater tidal current turbines), and a tidal reef at a variety of sites along the estuary.

The tidal reef is a radical new application of existing tidal range technology. The concept, as proposed to the feasibility study, uses fixed flow turbines that operate on a two-metre constant head difference, which is maintained by floating concrete caissons or movable 'crest gates'. It would operate on both the ebb and flood tides. In hydraulic terms, the head attained at the reef would be controlled by the rate of flow through the reef and the head differential across the turbines. This proposal is at an early stage of development, with no prototype. A report, commissioned by the Royal Society for the Protection of Birds and published in November 2008 by Atkins Engineering, also considered the tidal reef proposal (See www.rspb.org.uk/Images/atkins_tcm9-203975.pdf.) It flagged several technical issues and uncertainties with the concept and proposed a rather different design. The report suggested adapting and scaling up very low head hydro turbines such as those being developed at Millau in view of their potential environmental benefits.
(See www.vlh-turbine.com/EN/php/News.php)

These proposed schemes are in varying stages of development, with some using tried and tested technology, and others using tested structures but completely new materials. Some proposals are based on embryonic technologies that have not been prototyped or deployed, let alone at the huge scale proposed. Locations vary too, with the largest schemes spanning the Estuary from Minehead to Aberthaw (24 km, or 15 miles) and the smallest lying upstream of the Severn road crossings. Energy outputs also vary with the largest option (the Outer Barrage) estimated to generate up to 7% of UK electricity and the smallest generating roughly the same output as a large fossil fuel power plant.

However, careful consideration of the benefits, consequences, risks and costs of any Severn tidal power project is needed. The Severn Estuary is an internationally important nature conservation site for the species that occur there, including migratory fish and over-wintering birds, and for its estuarine habitats including mudflat and saltmarsh. The impact of both barrages and lagoons would be to retain water: low tide levels would rise slightly within impounded areas and overall high tide levels would be reduced by about a metre. Some areas of habitat currently uncovered at low tide would be permanently underwater, displacing bird populations. The passage of migratory fish, like eel and Atlantic salmon, would be impeded by any structures that cross the estuary and high mortality rates for some species may be expected without mitigating measures. Impacts on protected sites would need to be compensated for under environmental protection legislation, which safeguards our biodiversity and water quality. The environmental effects of the innovative technology schemes – the tidal reef and tidal fence – are currently unclear as these proposals are less detailed, but they may be less environmentally damaging than barrages or lagoons.

The Severn Tidal Power Study will assess in broad terms the costs, benefits and impact of the schemes, including environmental, social, regional, economic and energy market impacts. It will consider what measures the government could put in place to bring forward a scheme that fulfils regulatory requirements and it will include a strategic environmental assessment to ensure a detailed understanding of the estuary's environmental resource, recognising the nature conservation significance of the estuary.

UK Proposals Outside the Severn Estuary

As mentioned above, the Sustainable Development Commission report identified a number of other potential tidal power sites in the UK. A more recent study in the UK looking at tidal potential in the Eastern Irish sea has also set out the potential in the northwest of England (See www.liv.ac.uk/engdept/nwteg_launch_2008_po.pdf). The study particularly mentions the Mersey Estuary on which a feasibility study is currently being carried out (See www.merseytidalpower.co.uk/). Peel Environmental Ltd and the Northwest Regional Development Agency came together to commission a preliminary study that explores the opportunities for renewable energy and embraces the environmental, shipping and socio-economic aspects of any possible schemes. The largest of a number of options reported to be under consideration is a 700 MW tidal barrage.

Other potential tidal energy projects in the northwest include the Solway Firth, Morecambe Bay and the Wyre estuary. Regarding the east coast, projects have been suggested for the Humber, the Wash and the Thames.

The Development of Wave Energy Utilisation

António F. de O. Falcão
IDMEC, Instituto Superior Técnico, Technical University of Lisbon, 1049-001 Lisbon, Portugal
antonio.falcao@ist.utl.pt

Introduction

The energy from surface waves is the most conspicuous form of ocean energy, possibly because of the often spectacular destructive wave effects. The waves are produced by wind action and are therefore an indirect form of solar energy.

The possibility of converting wave energy into usable energy has inspired numerous inventors: more than one thousand patents had been registered by 1980 [1] and the number has increased markedly since then.

Yoshio Masuda may be regarded as the father of modern wave energy technology, with studies in Japan since the 1940s. He developed a navigation buoy powered by wave energy, equipped with an air turbine, which was in fact later named as a (floating) oscillating water column (OWC). These buoys were commercialised in Japan since 1965 (and later in USA) [2].

The oil crisis of 1973 induced a major change in the renewable energies scenario and raised interest in large-scale energy production from waves. The British government started in 1975 an ambitious research and development programme in wave energy [3] (followed shortly afterwards by the Norwegian government), but its funding came almost to a halt by 1982.

In Norway, the activity went on to the construction in 1985 of two full-sized (350 and 500 kW rated power) shoreline prototypes near Bergen. In the following years, until the early 1990s, activity in Europe remained mainly at the academic level, the most visible achievement being a small (75 kW) OWC shoreline prototype deployed at the island of Islay, Scotland (commissioned in 1991) [4]. At about the same time, two OWC prototypes were constructed in Asia: a 60 kW converter integrated into a breakwater at the port of Sakata, Japan, [5] and a bottom-standing 125-kW plant at Trivandrum, India [6].

The situation in Europe was dramatically changed by the decision made in 1991 by the European Commission to include wave energy in their research and development programme on renewable energies. Since then, about 30 projects on wave energy were funded by the European Commission involving a large number of teams active in Europe.

In the last few years, growing interest in wave energy is taking place in USA, Canada, South Korea, Australia, New Zealand, Brazil, Chile, Mexico and other countries.

The Wave Energy Resource

The main disadvantage of wave power, as with the wind from which is originates, is its (largely random) variability in several time-scales: from wave to wave, with sea state, and from month to month (although patterns of seasonal variation can be recognised).

The studies aiming at the characterisation of the wave energy resource, having in view its utilisation, started naturally in those countries where the wave energy technology was developed first. This was notably the case of the United Kingdom [7,8]. The WERATLAS, a European Wave Energy Atlas, whose preparation was funded by the European Commission in the mid-1990s, remains a basic tool for wave energy planning in Europe [9]. More detailed wave energy atlases (including the near-shore and shoreline resources) were produced later in several countries for national purposes.

The wave energy level is usually expressed as power per unit length (along the wave crest); typical values for “good” offshore locations (annual average) range between 20 and 70 kW/m and occur mostly in moderate to high latitudes. Seasonal variations are in general considerably larger in the northern than in the southern hemisphere [10], which makes the southern coasts of South America, Africa and Australia particularly attractive for wave energy exploitation.

Hydrodynamics

The study of the hydrodynamics of floating wave energy converters could benefit from previous studies on the, largely similar, dynamics of ships in wavy seas, which took place in the decades preceding the mid-1970s. The presence of a power take-off mechanism (PTO) and the requirement of maximising the extracted energy introduced additional issues.

The first theoretical developments addressed the energy extraction from regular (sinusoidal) waves with a linear PTO. An additional assumption of the theory was small amplitude waves and motions. This allowed the linearisation of the governing equations and the use of frequency-domain analysis. Since, in practice, most converters are equipped with strongly nonlinear mechanisms, a time-domain theory had to be developed. The time-domain model produces time-series and is the appropriate tool for active-control studies of converters in irregular waves. However it requires much more computing time as compared with the frequency-domain analysis. The standard text on the theoretical hydrodynamics of wave energy is [11].

Large numbers of devices in arrays are required if wave energy is to provide a significant contribution to large electrical grids. The hydrodynamic interaction between devices in array is extremely complex and approximate methods have to be devised in practice, such as the multiple-scattering method, the plane-wave method and the point-absorber approximation [12].

The utilisation of wave energy involves a chain of energy conversion processes, each of which is characterised by its efficiency as well as the constraints it introduces, and involves control procedures. Particularly relevant is the hydrodynamic process of wave energy absorption. The early theoretical studies on oscillating-body and OWC converters revealed that, if the device is to be an efficient absorber, its own frequency of oscillation should match the frequency of the incoming waves, i.e. it should operate at near-resonance conditions. The amount of absorbed wave energy can be significantly increased by adequately controlling the PTO in order to achieve near-resonance [13]. Phase control (including latching control) in real random waves is a difficult theoretical and practical problem that is far from having been satisfactorily solved.

In the development and design of a wave energy converter, the energy absorption may be studied theoretically/numerically, or by testing a physical model in a wave basin or wave flume. The techniques to be applied are not very different from those in the hydrodynamics of ships in a wavy sea. Numerical modelling is to be applied in the first stages of the plant design. The main limitations lie in its being unable to account for losses in water due to real (viscous) fluid effects (large eddy turbulence) and not being capable to model accurately large amplitude water oscillations (nonlinear waves). Such effects are known to be important (they also occur in naval engineering and in off-shore structures, where more or less empirical corrections are currently applied). For these reasons, model tests (scales 1:80 to 1:10) are carried out in a wave basin when the final geometry of the plant is already well established. As the development of the wave energy converter progresses towards the prototype construction stage, the need for large-scale testing requires the use of very large laboratory facilities. This was the case, in Europe, of the large wave tanks in Trondheim, Norway, and Nantes, France.

The Various Technologies

Unlike large wind turbines, there is a wide variety of wave energy technologies, resulting from the different ways in which energy can be absorbed from the waves, and also depending on the water depth and the location (shoreline, near-shore, offshore). Recent reviews identified about 100 projects at various stages of development. The number does not seem to be decreasing: new concepts and technologies replace or outnumber those that are being abandoned.

Several methods have been proposed to classify wave energy systems, according to location, to working principle and to size ("point absorbers" versus "large" systems). The classification in Table 1 is based mostly on working principle. The examples shown are not an exhaustive list and were chosen from the projects that have reached the prototype stage or at least were the object of extensive development effort.

First Generation Devices

Most of the first prototypes to be built and deployed in open coastal waters are or were located on the shoreline or near shore, and are sometimes named "first generation" devices [14]. In general they stand on the sea bottom or are fixed to a rocky cliff. Shoreline devices have the advantage of easier maintenance and installation and do not require deep-water moorings and long underwater electrical cables. The less energetic wave climate at the shoreline can be partly compensated by natural wave energy concentration due to refraction and/or diffraction (if the device is suitably located for that purpose). The typical first-generation device is the oscillating water column (OWC). Another example is the overtopping device Tapchan (Tapered Channel Wave Power Device) [15], a prototype of which (rated 350 kW) was built on the Norwegian coast in 1985 and operated for several years.

Oscillating water column (with air turbine)	Fixed structure	Isolated: **Pico, LIMPET**
		In breakwater: **Sakata, Mutriku**
	Floating: **Mighty Wale, Ocean Energy, Sperboy, Oceanlinx**	
Oscillating bodies (with hydraulic motor, hydraulic turbine, linear electrical generator)	Floating	Essentially translation (heave): **AquaBuoy, IPS BUoy, FO3, Wavebob, PowerBuoy**
		Essentially rotation: **Pelamis, PS Frog, SEAREV**
	Submerged	Essentially translation (heave): **AWS**
		Rotation (bottom-hinged): **WaveRoller, Oyster**
Overtopping (with low-head hydraulic turbine)	Fixed structure	Shoreline (with concentration): **TAPCHAN**
		In breakwater (without concentration): **SSG**
	Floating structure (with concentration): **Wave Dragon**	

Table 1 – Wave energy technologies

The oscillating water column (OWC) device comprises a partly submerged concrete or steel structure, open below the water surface, inside which air is trapped above the water free surface. The oscillating motion of the internal free surface produced by the incident waves makes the air flow through a turbine that drives an electrical generator**.** The axial-flow Wells turbine, invented in the late 1970s [16], has the advantage of not requiring rectifying valves. It has been used in almost all prototypes.

Full-sized OWC prototypes were built in Norway (in Toftestallen, near Bergen, 1985), Japan (Sakata port, 1990) [17], India (Vizhinjam, near Trivandrum, Kerala state, 1990) [6], Portugal (Pico, Azores, 1999) [18], UK (the LIMPET plant in Islay island, Scotland, 2000) [19]. The largest of all (2 MW), a nearshore bottom-standing plant (named Osprey) was destroyed by the sea (in 1995) shortly after having been towed and sunk into place near the Scottish coast. Smaller shoreline OWC prototypes (also equipped with Wells turbine) were built in Islay, UK (1991) [20], and more recently in China. The Australian company Energetech developed a technology using a large parabolic-shaped collector to concentrate the incident wave energy (a prototype was tested at Port Kembla, Australia, in 2005).

In the present situation, the civil construction dominates the cost of the OWC plant. The integration of the plant structure into a breakwater has several advantages: the construction costs are shared, and the access for construction, operation and maintenance of the wave energy plant become much easier. This has been done successfully for the first time in the harbour of Sakata, Japan (in 1990), where one of the caissons making up the breakwater had a special shape to accommodate the OWC and the mechanical and electrical equipment. The option of the "breakwater OWC" was adopted in the 750 kW OWC plant planned to be installed in the head of a new breakwater in the mouth of the Douro river (northern Portugal) [21] and in the newly built breakwater at Mutriku port, in northern Spain [22].

Oscillating-body Systems

Offshore devices (sometimes classified as third generation devices) are basically oscillating bodies, either floating or (more rarely) fully submerged. They exploit the more powerful wave regimes available in deep water (typically more than 40 m water depth). Offshore wave energy converters are in general more complex compared with first-generation systems. This, together with additional problems associated with mooring, access for maintenance and the need of long underwater electrical cables, has hindered their development, and only in the last few years have some systems reached, or come close to, the full-scale demonstration stage.

There is a substantial variety of typical offshore wave-energy devices, some of which have reached, or are close to, the prototype stage. In most cases, there is a mechanism that extracts energy from the relative oscillating motion between two bodies. This is the case of the Pelamis, developed in the UK, a snake-like slack-moored articulated structure composed of four cylindrical sections linked by hinged joints, and aligned with the wave direction. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors driving electrical generators [23, 24]. Sea trials of a full-sized prototype (120 m long, 3.5 m diameter, 750 kW rated power) took place in 2004. A set of three Pelamis devices was deployed off the Portuguese northern coast in September 2008, making it the first grid-connected wave farm worldwide (Figure 1).

Figure 1. The three-unit 3 750 kW Pelamis wave farm in calm sea off northern Portugal, 2008.

Several concepts use the heaving motion of a slack-moored axisymmetric buoy reacting against the inertia of another body (Figure 2). In the case of the Powerbuoy (developed in USA) [25], the second body is a submerged disc, whereas the Wavebob [26] (an Irish concept) consists of two co-axial axisymmetric floating bodies oscillating differently. In both cases, the PTO consists of a high-pressure oil hydraulic circuit, with rams and a hydraulic motor. The Aquabuoy is a device that combines two concepts developed in Sweden: the IPS buoy and the hose pump, which were tested in the sea at about half-scale in 1982 [27]. The Aquabuoy consists of a buoy, whose heave oscillations, by reaction against the inertia of the water inside an acceleration tube (located beneath the buoy), produce high-pressure water flow by means of a pair of hose pumps [28]. This is converted into electrical energy by a conventional Pelton turbine driving an electrical generator. A prototype was built and tested in 2007 off the coast of Oregon, USA.

In some cases, the device consists of a set of heaving buoys reacting against a common frame and sharing a common PTO. This is the case of FO3 [29] (mostly a Norwegian project, in which the frame is a large floating structure with very low resonance frequency), of the Danish Wave Star [30] (the frame stands of the bottom) and the Brazilian hyperbaric device whose frame is a breakwater [31]. These are recent devices equipped with pressurised hydraulic systems, the first one having been tested at 1/3 scale and the last two at 1/10 scale.

The Archimedes Wave Swing (AWS) [32], basically developed in Holland, is a fully-submerged device consisting of an oscillating upper part (the floater) and a bottom-fixed lower part (the basement). The floater is pushed down under a wave crest and moves up under a wave trough. This motion is resisted by a linear electrical motor, with the interior air pressure acting as a spring. A prototype, rated 2 MW (maximum instantaneous power) was deployed and tested in 2004 off northern Portugal. The AWS was the first converter

Figure 2. Heaving point-absorber prototypes: Powerbuoy, Wavebob and Aquabuoy.

to use a linear electrical generator, a technology that is being developed by other teams (University of Edinburgh, UK, Uppsala University, Sweden, and Oregon State University, USA) for wave energy applications.

Except for the Pelamis, the oscillating-body devices mentioned above absorb energy essentially from the heaving mode of oscillation. Other modes, namely pitching and surge, can also be used. This is the case of the French system named Searev [33], a large floating device enclosing a heavy horizontal-axis wheel behaving like a mechanical pendulum. The rotational motion of the pendulum relative to the hull activates a hydraulic PTO.

The Oyster (UK) [34] and the Waveroller (Finland) [35] are devices based on the inverted pendulum, designed to be located near-shore in water depths of 10 to 12 m. The concept consist of a flap-shaped buoyant body hinged at the sea bottom, whose pitching motion, activated by waves, drives a hydraulic ram that pumps high-pressure fluid (sea water in the case of Oyster, oil in Waveroller). A 10 to 15 kW prototype of the Waveroller was tested in the sea in Portugal in 2007. A full-sized prototype of Oyster (300 to 600 kW) was recently built in Scotland.

Floating OWCs

The early OWCs developed in Japan before 1980 by Yoshio Masuda were floating devices. Interest in the floating OWC has not died out. The so-called Mighty Whale, built in Japan in the 1998, and tested in the sea for several years [36], is in fact a floating version of the OWC (50 m long, 30 m wide structure), equipped with three Wells turbines, each driving a 30 kW electrical generator.

The Backward Bent Duct Buoy (BBDB), originally a Japanese concept, has been the object of more recent interest in Europe, under the name OE buoy [37]: a 15 m long 1/4-scale pilot plant, equipped with a Wells turbine, has been built in Ireland and has been tested since November 2006 in the sheltered waters of Galway Bay (western Ireland).

The Sperboy is a floating OWC being developed in UK [38] that uses several vertical columns of different lengths to more effectively capture energy from a range of wavelengths. A $1/5^{th}$ scale pilot unit has been deployed at sea in southern England.

Overtopping Devices

The working principle of overtopping devices is very different from OWCs and oscillating bodies. Overtopping or run-up is a non-linear phenomenon that cannot be modelled by linear wave theory, and so requires different modelling tools. An overtopping device acts basically as a pump that converts wave energy into potential energy in a water reservoir whose main function is to provide a stable supply to a conventional low-head hydraulic turbine (or a set of turbines).

In the Tapchan (mentioned above), the run-up effect is produced by a gradually narrowing channel with wall heights equal to the filling level of the reservoir (about 3 m in the Norwegian prototype) such that as the waves propagate down the channel their height is amplified until the wave crests spill over the walls and fill the water reservoir.

In other devices, the run-up effect takes place along a sloping wall or ramp, as is the case of the Wave Dragon [39], an offshore floating system developed mostly in Denmark. The Wave Dragon consists of a floating slack-moored platform with two long arms acting as wave reflectors to focus the waves towards a ramp. A 1:4.5-scale model, 57 m-wide, equipped with seven turbines, was deployed in 2003 off the Danish coast in the North Sea and tested for a couple of years. Plans to construct of a multi-MW full-sized device have been announced.

The Seawave Slot-cone Generator (SSG) [40] is a Norwegian breakwater-version of the run-up concept that utilises multiple reservoirs placed on top of each other, into which the water overspills through slots spaced at different levels on the sloping sea-facing side of the breakwater. The device is equipped with a special multi-stage vertical-axis turbine.

Equipment

The energy of sea waves can be absorbed by wave energy converters in a variety of manners, but in every case the transferred power is highly fluctuating in several time-scales, especially the wave-to-wave or the wave group time-scales. In most devices developed or considered so far, the final product is electrical energy to be supplied to a grid. So, unless some energy storage system is available, the fluctuations in absorbed wave power will appear unsmoothed in the supplied electrical power, which severely impairs the energy quality and value from the viewpoint of the grid. In other devices, it requires the peak power capacity of the electric generator and power electronics to greatly exceed the time-averaged delivered power. In practice, three methods of energy storage have been adopted in wave energy conversion.

An effective way is storage as potential energy in a water reservoir, which is achieved in overtopping devices, equipped with more or less conventional low-head hydraulic turbines, capable of attaining a peak efficiency close to 90%.

In the oscillating water column type of device, the size and rotational speed of the air turbine rotor make it possible to store a substantial amount of energy as kinetic energy (flywheel effect); this is particularly true for the Wells turbine, whose rotor diameter and blade tip speed are both substantially larger compared with the self-rectifying impulse turbine (that has been proposed as an alternative to the Wells turbine). These self-rectifying air turbines are relatively robust and mechanically simple pieces of equipment. However, they are subject to much more demanding conditions than the turbines in any other application, including wind turbines. Indeed the flow through the turbine is reciprocating and is random and highly variable over several time scales, ranging from a few seconds to seasonal variations. It is not surprising that the time-average efficiency of an air turbine in an OWC has been found to be relatively low, in general not exceeding about 50%. This is a technical area with substantial room for improvement.

In a large class of devices, the oscillating (rectilinear or angular) motion of a floating body (or the relative motion between two moving bodies) is converted into the flow of a liquid (water or oil) at high pressure by means of a system of hydraulic rams (or equivalent devices). At the other end of the hydraulic circuit there is a hydraulic motor (or a high-head Pelton water-turbine) that drives an electric generator. The highly fluctuating hydraulic power produced by the reciprocating piston (or pistons) may the smoothed by the use of a gas accumulator system, which allows a more regular production of electrical energy. Naturally the smoothing effect increases with the accumulator volume and working pressure. High-pressure oil is the working fluid in the Pelamis, Wavebob, Powerbuoy, Wave Star devices, whereas sea water is used in the PTO of Aquabuoy and the Brazilian multi-body hyperbaric device. This type of PTO may be regarded as unconventionally using conventional equipment. Hydraulic motors (including variable displacement versions, particularly suitable for oil flow control) are commercially available up to several hundred kW, while Pelton turbines exist that cover a very wide range of power levels. In both cases, peak efficiencies can reach close to 90%, although the efficiency can drop significantly at partial loads. The gas accumulator system may represent a substantial part of PTO cost.

In most wave energy devices, a more or less conventional electrical generator is used to produce electricity. Variable rotational speed is frequently adopted, the technology (and the power range) being basically similar to wind energy applicactions.

Some devices use direct electrical energy conversion by means of linear electrical generators (this was pioneered in Holland for the Archimedes Wave Swing device). These machines are still at the development level. Such PTO systems do not require an intermediate mechanical system and may attain a high efficiency. On the other hand, the energy storage capability is small (or very expensive), which may result in a high peak-to-average power ratio and in poor quality of the electrical power supplied to the grid.

Conclusion

Unlike the case of wind energy, the present situation shows a wide variety of wave energy systems, at several stages of development, competing against each other, without it being clear which types will be the final winners.

In general, the development, from concept to commercial stage, has been found to be a difficult, slow and expensive process. Although substantial progress has been achieved in the theoretical and numerical modelling of wave energy converters and of their energy conversion chain, model testing in wave basin a time-consuming and considerably expensive task is still essential. The final stage is testing under real sea conditions. In almost every system, optimal wave energy absorption involves some kind of resonance, which implies that the geometry and size of the structure are linked to wavelength. For these reasons, if pilot plants are to be tested in the open ocean, they must be full-sized structures. For the same reasons, it is difficult, in the wave energy technology, to follow what was done in the wind turbine industry (namely in Denmark): relatively small machines where developed first, and were subsequently scaled up to larger sizes and powers as the market developed. The high costs of constructing, deploying, maintaining and testing large prototypes, under sometimes very harsh environmental conditions, has hindered the development of wave energy systems; in most cases, such operations were possible only with substantial financial support from governments (or, in the European case, from the European Commission).

Unit costs of produced electrical energy claimed by technology development teams are frequently unreliable. At the present stage of technological development and for the systems that are closer to commercial stage, it is widely acknowledged that the costs are about three times larger than those of energy generated from the onshore wind (the gap is smaller in comparison with offshore wind). It is not surprising that the deployment of full-sized prototypes under open ocean conditions has been taking (or is planned to take) place in coastal areas of countries where specially generous feed-in tariffs are in force, and/or where government supported infrastructures (especially cable connections) are available for testing.

References

1. McCormick, ME. Ocean Wave Energy Conversion. New York: Wiley, 1981.

2. Masuda, Y. Wave-activated generator. Int. Colloq. on the Exposition of the Oceans, Bordeaux, France, 1971.

3. Grove-Palmer, COJ. Wave energy in the United Kingdom: a review of the programme June 1975 to March 1982. Proc. 2nd Int. Symp. Wave Energy Utilization, Trondheim, Norway, 1982, p. 23-54.

4. Whittaker, TJT, McIlwaine, SJ, Raghunathan, S. A review of the Islay shoreline wave power station. Proc. First European Wave Energy Symp., Edinburgh, 1993, p. 283-286.

5. Ohneda, H, Igarashi, S, Shinbo, O, Sekihara, S, Suzuki, K, Kubota, H, Ogino, H, Morita, H. Construction procedure of a wave power extracting caisson breakwater. Proc. 3rd Symp. Ocean Energy Utilization, Tokyo, 1991, p. 171-179.

6. Ravindran, M, Koola, PM. Energy from sea waves – the Indian wave energy program. Current Sci 1991; 60: 676-680.

7. Mollison, D, The prediction of device performance. In: Power from Sea Waves (B. Count, Ed.). Academic Press, London, 1980, p. 135-172.

8. Mollison, D, Wave climate and the wave power resource. In: Hydrodynamics of Ocean Wave Energy Utilization (D.V. Evans and A.F. de O. Falcão, Eds). Berlin: Springer, 1986, p. 133-167.

9. Pontes, MT. Assessing the European wave energy resource. Trans ASME J Offshore Mech Arct Eng 1998; 120: 226-231.

10. Barstow, S, Gunnar, M, Mollison, D, Cruz, J. The wave energy resource. In: Ocean Wave Energy (Cruz J, ed.). Berlin: Springer, 2008, p. 93-132.

11. Falnes, J. Ocean Waves and Oscillating Systems. Cambridge: Cambridge University Press, 2002.

12. Mavrakos, SA, McIver, P. Comparison of methods for computing hydrodynamic characteristics of arrays of wave power devices. Appl Ocean Res 1997; 19: 283-291.

13. Falnes, J. Optimum control of oscillation of wave energy converters. Int J Offshore Polar Engng 2002; 12: 147-155.

14. Falcão, AF de O. First-generation wave power plants: current status and R&D requirements. Trans ASME J Offshore Mech Arct Eng 2004; 126: 384-388.

15. Mehlum, E. TAPCHAN. In: Hydrodynamics of Ocean Wave Energy Utilization (DV Evans and AF de O. Falcão, Eds). Berlin: Springer, 1986, p. 51-55.

16. Wells, AA. Fluid driven rotary transducer. British Patent Spec. 1 595 700, 1976.

17. Ohneda, H, Igarashi, S, Shinbo, O, Sekihara, S, Suzuki, K, Kubota, H, Ogino, H, Morita, H. Construction procedure of a wave power extracting caisson breakwater. In: Proc. 3rd Symp. Ocean Energy Utilization, Tokyo, 1991, p. 171-179.

18. Falcão, AF de O. The shoreline OWC wave power plant at the Azores. In: Proc. 4th European Wave Energy Conf., Aalborg, Denmark, 2000, p. 42-47.

19. Heath, T, Whittaker, TJT, Boake, CB. The design, construction and operation of the LIMPET wave energy converter (Islay, Scotland). In: Proc. 4th European Wave Energy Conf., Aalborg, Denmark, 2000, p. 49-55.

20. Whittaker, TJT, McIwaine, SJ, Raghunathan, S. A review of the Islay shoreline wave power station. In: Proc. (First) European Wave Energy Symp., Edinburgh, 1993, p. 283-286.

21. Martins, E, Silveira-Ramos, F, Carrilho, L, Justino, P, Gato L, Trigo L, Neumannn F. CEODOURO project: overall design of an OWC in the new Oporto breakwater. In: Proc. 6th European Wave and Tidal Energy Conference, Glasgow, August-September 2005.

22. http://www.fedarene.org/publications/Projects/NEREIDA/NEREIDA%20-%201st%20e-Newsletter/Nereida%20-%20e-Newsletter%201.htm

23. Pitzer, DJ, Retzler, C, Henderson, RM, Cowieson, FL, Shaw, MG, Dickens, B, Hart, R. Pelamis wave energy converter: recent advances in the numerical and experimental modelling programme. In: Proc. 6th European Wave and Tidal Energy Conference, Glasgow, 2005, p. 373-378.

24. Yem, R. Pelamis. In: Ocean Wave Energy (Cruz J, ed.). Berlin: Springer, 2008, p. 304-321.

25. http://www.oceanpowertechnologies.com/

26. http://www.wavebob.com/

27. Cleason, L, Forsberg, J, Rylander, A, Sjöström, BO. Contribution to the theory and experience of energy production and transmission from the buoy-concept. In: Proc. 2nd Int. Symp. Wave Energy Utilization, Trondheim, Norway, 1982, p. 345-370.

28. Weinstein, A, Fredrikson, G, Parks, MJ, Nielsen, K. AquaBuOY, the offshore wave energy converter numerical modelling and optimization. Proc. MTTS/IEEE Techno-Ocean '04 Conference, Kobe, Japan, 2004, vol. 4, p. 1854-1859.

29. http://www.seewec.org/index.html

30. http://www.wavestarenergy.com/

31. Estefen, SF, Esperança, PTT, Ricarte, E, Costa, PR, Pinheiro, MM, Clemente, CH, Franco, D, Melo, E, Souza, JA. Experimental and numerical studies of the wave energy hyperbaric device for electricity production. In: Proc. 27th Int. Conf. Offshore Mechanics Arctic Engineering, Estoril, Portugal, 2008, Paper No. OMAE2008-57891.

32. Prado, M. Archimedes Wave Swing (AWS). In: Ocean Wave Energy (Cruz J, ed.). Berlin: Springer, 2008, p. 297-304.

33. Ruellan, A, Ben Ahrned, H, Multon, B, Josset, C, Babarit, A, Clement, AH. Design methodology for a SEAREV wave energy converter. In: IEEE IEMDC 2007: Proc. Int. Electric Machines and Drives Conf, 2007**,** p. 1384-1389.

34. http://www.aquamarinepower.com/

35. http://www.aw-energy.com/page_1_0.html

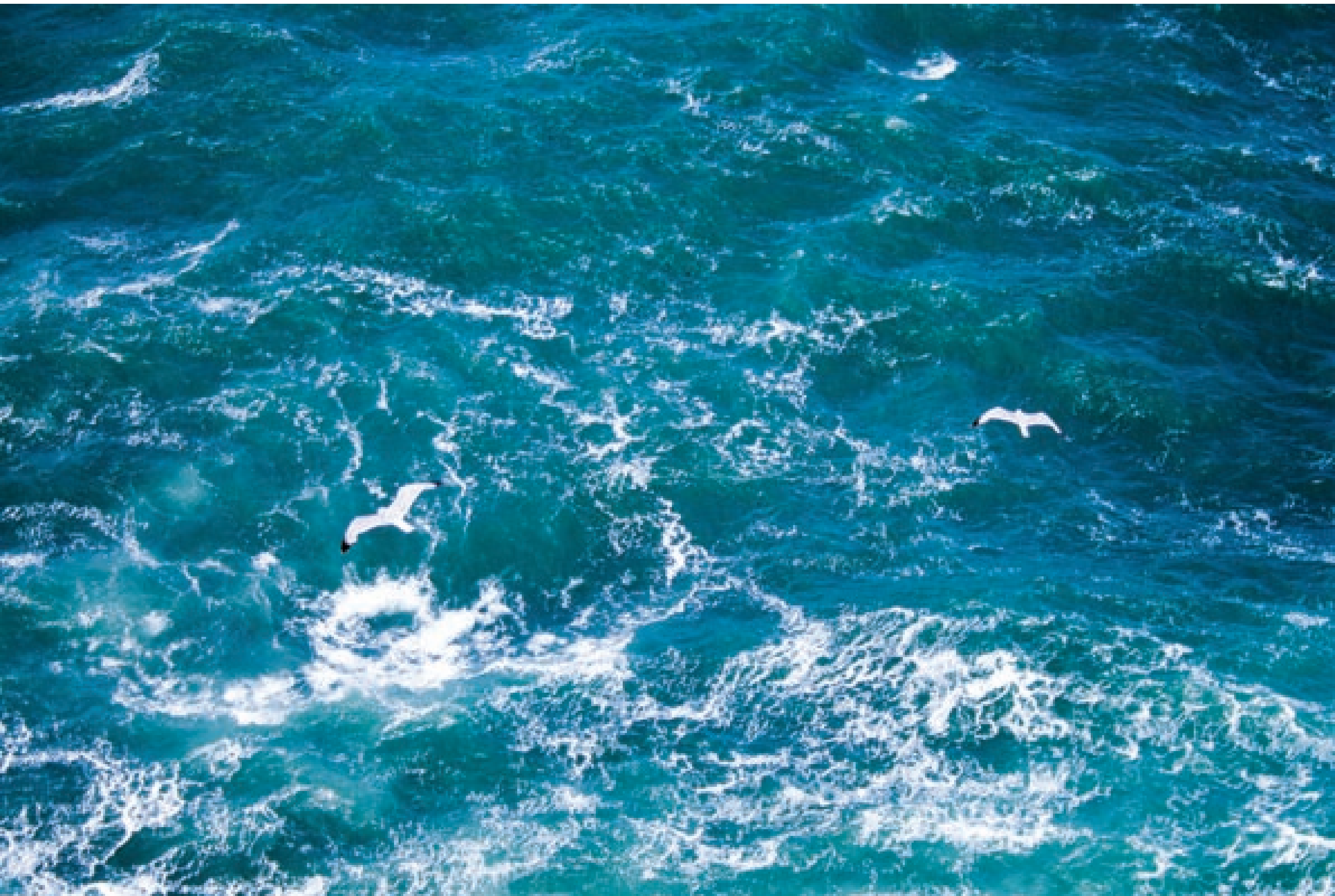
36. Washio, Y, Osawa, H, Nagata, Y, Fujii, F, Furuyama, H, Fujita, T. The offshore floating type wave power device "Mighty Whale": open sea tests. In: Proc. 10th Int. Offshore Polar Engng Conf., Seattle, 2000, vol. 1, p. 373-380.

37. http://www.oceanenergy.ie/

38. http://www.sperboy.com/

39. Tedd, J, Friis-Madsen, E, Kofoed, JP, Knapp, W. Wave Dragon. In: Ocean Wave Energy (Cruz J, ed.). Berlin: Springer, 2008, p. 321-335.

40. http://www.waveenergy.no/



The Status of Tidal Stream Energy Conversion

Professor A S Bahaj
The University of Southampton
Sustainable Energy Research Group, School of Civil Engineering and the Environment
Southampton SO17 1BJ, United Kingdom

Introduction

Energy and climate change are currently two of the most important issues facing society. Many governments around the world have set targets for emission reductions and the production of electricity from renewable resources. The development of low carbon technologies that can result in reductions in emissions whilst contributing to energy security – especially if derived indigenously – occupy the centre ground in the policies of many governments. However, most policies are highly reliant on the expansion of large-scale wind energy supply with little attention paid to other areas of renewable energy.

Ocean energy, in the form of tidal stream (or marine current), tidal range and wave resource exploitation can, in addition to wind energy, deliver large amounts of power that could contribute to national and international targets. Globally, tidal dissipation on continental shelves has been estimated at 2.5 TW [1]. If 1to 2% of this could be tapped for power generation, tidal power could deliver 200 to 400 TWh/annum. The global wave energy resource has been estimated by the European Thematic Network on Wave Energy at 1.3 TW, with a technically exploitable resource of 100 to 800 TWh/annum [2, pages 289-290].

Marine current energy conversion devices are currently being tested at the prototype and pre-commercial demonstration stage at sea. There is also a thriving research and development community around the world undertaking both fundamental and applied research to support tidal and wave energy development. However, at present most technological innovation to exploit such resources is currently at an early stage of development, with only a small number of devices approaching the commercial demonstration stage. In addition, there is plethora of conversion philosophies that seem to dilute the available financial resources and result in inertia in technology progression to commercialisation.

This report provides a summary of the current status of the development of tidal stream energy conversion technologies, relevant research and development areas and some insight into other related issues, such as permissions, consents, finance and infrastructure.

Device Specific Issues	Project Specific Issues
> Energy capture	> Resource assessment
> Power take-off	> Economics modelling and financing
> Control systems	> Consents and permits
> Electrical conversion	> Environmental impact assessments
> Cable connection to sea-bed	> Stakeholder consultation
> Fixing/moorings	> Cable-routing
> Testing at scales	> Deployment and Maintenance
> Economics and financing	

Table 1: Important issues in device and project development

Prior to presenting the status update, it is worth stating some of the important issues that arise when undertaking work in this area. Table 1 summarises some of these in the context of marine current device development. Resource assessment is one of the essential components of any development project. Obviously a site could be selected due its partially known energetic potential – high or moderate flow velocity. However, there are many additional factors that also need consideration – proximity to a grid connection and ports, availability of vessels and an understanding of sea-bed conditions. Unlike fossil fuel electricity generation, the fuel in tidal stream electricity conversion – flow in the sea – is free and the revenue stream from a particular development is governed by the energy yield of the project. Furthermore, the overall cost of a tidal stream project is totally dominated by capital and operating costs. Since the revenue is mainly dependent on flow conditions, the profitability of a project is highly dependent on clear understanding of the site conditions including fluid flow characteristics. Hence, resource assessment is crucial to arrive at the required economic analysis that will indicate the viability or otherwise of a tidal stream project. Therefore, in addition to giving the technology and research and development status, this report will also briefly give some consideration to one of these issues – resource assessment.

Resource Assessment

Resource assessments produced by developers are in many cases subject to commercial confidentiality. Recently, work has started to standardise resource assessment methodologies through the drafting of new protocols [3, 4]. However, these are still in the early stages of development. The gathering and analysis of field data on tidal streams is an ongoing process with Acoustic Doppler Current Profiling (ADCP) surveys carried out in many favourable locations [5].

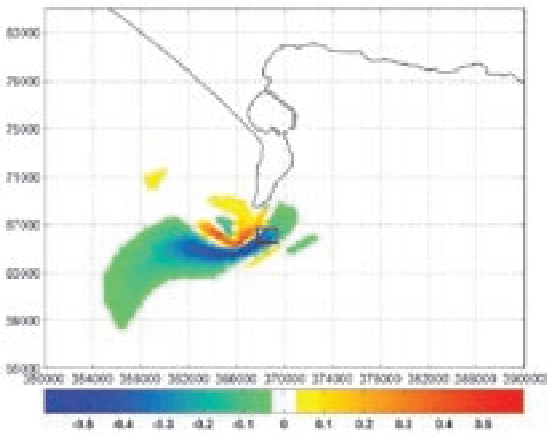


Fig 1 (a). Difference in flow speed with respect to natural state, when energy is extracted. Portland Bill, UK, [7].

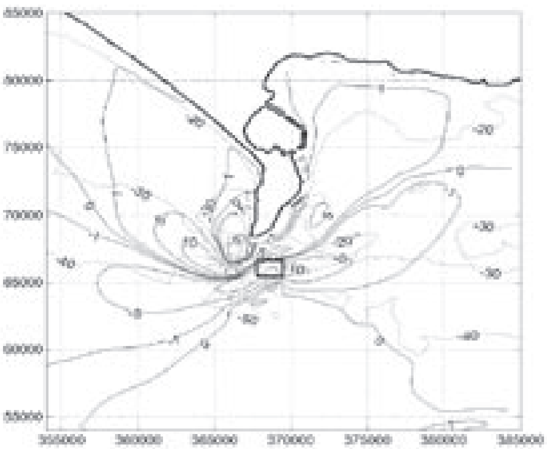


Fig. 1 (b). Percentage decrease in major axis of tidal ellipse with energy extraction. Portland Bill, UK, [7].

In many locations, available data on tidal streams is sparsely distributed and is rarely in primary form. Simple interpolation is an option in such cases, as used in resource assessments such as [6], but may be inaccurate where there are significant changes in topography and flow velocity in space.

Before an expensive hydrographic survey is commissioned – which is limited to a small area of sea and carries the risk of no data return – it would be desirable to obtain a first estimate of the resource over an area wide enough to include all possible generator locations, but with resolution detailed enough to include details of the flow at spatial and temporal scales relevant to an array of turbines.

Numerical modelling of tidal flows can constrain sparse data with the known dynamics of fluids, giving a high resolution picture of the available resource. It also offers the potential to examine the effects of arrays of turbines on the flow itself, providing the turbines can be adequately represented. As an example, such an approach has been attempted for the Portland Bill site in the South of the UK, parameterising the turbine array as added roughness [7]. Fig.1 (a) indicates the results in terms of speed-difference when energy extraction is included, at a particular time-step during the simulation, while Fig.1 (b) shows the percentage change in tidal ellipse magnitude, superimposed on bathymetry contours. The latter indicates that measurable changes may persist for some kilometres downstream of an array.

Technology Status of Devices

This section reviews current projects and their development, giving brief highlights of frontrunner devices that are approaching the commercial demonstration stage, and also mentioning prototype and laboratory-scale devices. Most of the sources of the information presented are web pages, published articles and presentations at conferences and meetings.

Commercial and Prototype Devices

Currently available information on commercial prototype device development and deployment plans is summarised below and builds on the 2007 IEA-OES Annual Report [8]:

Project SeaGen (Marine Current Turbines Ltd, (MCT Ltd)) at Strangford Lough, Northern Ireland, UK, has successfully deployed a second-generation device consisting of a piled twin horizontal-axis two-bladed turbine converter of capacity 1.2 MW [9]. This project builds on experience gained over last five years with the 300 kW device installed at Lynmouth in the Bristol Channel, UK [10]. Initial indications from the Seagen project are that the systems are working well, with power being exported to the grid. The deployment apparently went well, in spite of delays and re-design of the piling process. A blade failure was reported during commissioning in July [11]; re-fitting of a new blade was achieved in November 2008 [12].

Over the last 12 months, the Irish company Open Hydro has been testing their open centred, rim generator device, capacity 250 kW, at the European Marine Energy Centre (EMEC) in the Orkneys.

At the recent ICOE conference in Brest (October 2008), the two companies indicated that they are the front-runners in tidal stream technologies, having devices in the sea and producing electricity, with Open Hydro being the first to export electricity to the UK grid [13]. However, in spite of some months in operation, neither Open Hydro nor MCT Ltd were in a position to present to the audience either operational or performance data on their devices.

Several new tidal stream devices have also entered the field in 2008: Hydrohelix has tested a 3-m diameter device in Brittany [14]; OceanFlowEnergy have deployed a 1/10-scale floating device in Strangford Narrows [15]; Pulse Tidal have recently started the installation of its 100-kW oscillating hydrofoil generator in the River Humber [16]. Meanwhile in Canada, Clean Current has re-deployed its 65-kW device after a refit due to initially disappointing performance of water lubricated bearings [17]. In the southern hemisphere, Atlantis Resources Corporation has achieved what it claims is a world record of towing tests in the sea of its 400-kW Nereus II and 500-kW Solon prototype turbines [18]. ScotRenewables SRTT, a 1.2-MW floating device, will be tested at EMEC in 2010 [19]. Verdant Power, had six of its 35-kW turbines installed in the East River NY, USA, in 2006/7. Reports indicate multiple failures but a retrofit with new blades was accomplished in September 2008 [20]. The Netherlands-based company Tocardo BV has this year established a subsidiary in Wick, Scotland, with a view to developing a 10-MW farm in the Pentland Firth. Meanwhile, they have begun production of three pre-commercial 35-kW units for testing in a sluice gate intake on Den Oever, Netherlands, the same location that the original 2.8-m prototype was tested in 2005 [21].

A number of large tidal stream developments are planned over the next five years. Lunar Energy and E.ON are developing a farm of eight 1-MW turbines off the coast of Pembrokeshire, Wales, UK [22]. Meanwhile, further north but still in Welsh waters, MCT Ltd and Npower will be working to install a tidal farm of seven of the third-generation SeaGen 1.5-MW turbines off the coast of Anglesey to enter operation by 2012 [23]. In September 2008, it was announced that Hammerfest Strøm, which has been quietly testing its turbine in northern Norway for the past four years, has partnered with ScottishPower and plans to develop 60 MW at three sites in the UK [24]. Across the Channel (or La Manche), Open Hydro has been selected by EDF to install four to ten of their scaled-up 1-MW turbines off the coast of Brittany [25].

Several developers are eyeing the Pentland Firth for commercial-scale deployments; Atlantis Resources Corp is looking for a partner in an innovative project to develop a 20-MW tidal farm to power a proposed new data-centre located in the far north of Scotland [26].

Both the east and west coasts of Canada hold enormous potential for tidal stream generation, but planned developments have been slower to progress than on the other side of the Atlantic. This is changing, with MCT Ltd and BC Tidal Corp planning to deploy at least three SeaGen units in Discovery Passage [27]. On the other coast, in the famous Bay of Fundy, up to three turbines are to be installed from 2009 by Open Hydro in partnership with Nova Scotia Power [28]; Clean Current [29] with a scaled up version of its device installed at Race Rocks; and Minas Basin Pulp and Power Co, possibly with a UEK device (although the latter is in doubt partly due to the death in November 2008 of the founder of UEK, Philippe Vauthier).

Looking further into the future, it was announced in March 2008 that Lunar Energy had signed a memorandum of understanding with Korean Midland Power to develop a 300-MW farm in Korea by 2015, which – if it goes ahead – will be by far the largest tidal stream development in the world [30]. Larger even than the newly installed 254-MW tidal scheme retro-fitted into an existing 11-km barrage in Sihwa Lake, Korea, due to be completed late 2009 [31]. Three further converted barrages, totalling 1.8 GW, are proposed to be built in Korea by 2014 [32]. Together, these developments will launch Korea well ahead of France as the world's leading nation for tidal generation.

The UK may not be far behind, however, as MCT Ltd has recently indicated that it intends to apply for a lease from the UK's Crown Estate to deploy its technology in to Scotland's Pentland Firth. The potential capacity figures quoted are up to 50 MW by 2015 and up to 300 MW by 2020 [33]. This is subject to securing the required finance, meeting the necessary approvals and the availability of an appropriate local grid connection at the site. Several consortia are also in the running for a tidal generation scheme on the River Severn, with proposed capacity varying from to 1 to 8 GW [34]. Not strictly in the UK, but closely related, Open Hydro and Alderney Renewable Energy plan to develop a 285-MW array in the waters of the Channel Island of Alderney [35].

All the above is extremely good progress with some welcome large projects being highlighted for development in the not too distant future. These are not only important for the maturity of the technology but also for providing the needed experience of operating in the sea. However, it remains to be seen how the current financial turmoil and bleak outlook for the world economy will impact upon the progress of the proposed large schemes.

Research and Development

Fundamental research and development are the backbone of both generating new knowledge and assessing devices at their early stage of development. This section aims to give some of the highlights in this area, by summarising new advances that are relevant to the development of tidal stream energy conversion.

In parallel with the developments in the commercial sector, many aspects of tidal stream power remain active areas of research. This research divides naturally between individual devices, device interactions and resource assessment. In the former category are the tests of the University of Strathclyde 2.5-m CoRMaT contra-rotating turbine and its smaller 0.92-m cousin, both major highlights at the tenth World Renewable Energy Congress in Glasgow in July 2008 [36]. Also in 2008, the University of Southampton carried out extensive tests on side-by-side dual 0.8-m rotors, as part of a UK, Technology Strategy Board-funded programme to determine wake interactions; publications will follow in due course [37]. Several teams are working on CFD simulations of tidal turbines, using developments of blade element momentum theory [38]; nested rotating reference frames within conventional RANS solvers [39, 40]; boundary element methods more commonly used to design ship propellers [41] and more exotic vortex methods [42, 43]. When considering the interaction of multiple devices, scale effects make experimental work challenging; nevertheless, work has progressed through the use of porous disk simulators and artificial roughness to physically model the evolution of the far wake of a tidal turbine influenced by the vertical flow profile [44, 45]. Multiple rows of tidal fences have also been tested in a similar fashion, and initial comparisons with CFD simulations have been made [46]. Resource assessment is necessarily more theoretical and uncertain in nature than the previous topics, as arrays of turbines are yet to be constructed. Research has been focussed on the limits to energy extraction in channels and bays [47]; on GIS mapping of the available resource taking into account the multitude of constraints on development [48]; the interaction of turbine performance with resource assessment [49]; and learning lessons from wind in how to parameterise the effects of large arrays on the flow [50].

Protocols

There have been a number of recent attempts at drafting protocols for fair evaluation of the tidal stream resource and the performance of tidal stream turbines at different stages of development [51, 52, 53]. It is the aim of the IEA and other stakeholders, after wide international consultation, for some of these to form the basis of international standards [3]. The standards will be assessed and propagated through the newly-formed Ocean Energy IEC committee (IEC TC 114) [54]. A major EU FP7 project entitled "Equitable Testing and Evaluation of Marine Energy Extraction Devices in Terms of Performance, Cost and Environmental Impact" (EquiMar, of which the author is a member), will further develop the protocols and best practice guidance, as data and experience from full-scale testing in the sea becomes available [55].

Planning, Consent and Financing

Most countries have their own processes for project approval. These vary and the number of stages needed to achieve approval or consent for a project is highly complex. Taking the UK as an example, there are a number of hurdles for developers to leap in order to install their device on the sea-bed. The sea-bed itself is the property of the Crown Estate (a government agency) which plans to grant exclusive leases over portions of it to tidal stream developers, provided certain conditions are met. Securing site leases from the Crown Estate requires the project developer to carry out comprehensive environmental impact assessments and monitoring, as well as assuring the Crown Estate of the appropriateness of the design, technical and operational integrity of the technology. On 17 November 2008, the Crown Estate announced a first round of development in the Pentland Firth, inviting developers to apply for pre-qualification [56]. Once the option to lease the sea-bed has been obtained, developers must obtain consents from either the Marine and Fisheries Agency (in England and Wales), or the Fisheries Research Services (Scotland), or the Northern Ireland Environment Agency. These consents include a licence under the Food and Environment Protection Act (mainly concerning drilling and foundations) and the Coast Protection Act (mainly for the electrical connection to shore). Obtaining these consents would involve at the least a detailed environmental statement based on survey data and possibly an appropriate assessment if required by the Habitats Directive. In the process of obtaining the consents, a wide variety of bodies would consulted, a process taking at least six months [57]. In addition, for developments greater than 1 MW, consent is required from BERR (possibly now DECC) under the Electricity Act. Local planning permission is also likely to be necessary for any onshore works, for example cable-routing to and construction of substations.

Finance is another major hurdle for both prototype development and project implementation. For example, in the UK some of the tidal stream technology variants (e.g. Lunar and SMD Hydrovision) that have market potential, and were supported under the previous BERR technology programme, are rumoured to be awaiting co-financing to support development of full-scale prototypes. Meanwhile, BERR's GBP 42 million Marine Renewables Deployment Fund, offering 25% capital grants up to GBP 5 million and revenue support of GBP 100/MWh, has – so far – had no takers [58]. Many countries have now introduced schemes to support new renewable technologies, including ocean energy or marine renewables; selected schemes are included in Table 2.

Conclusions

Tidal stream technology and the associated industry are still in their infancy. Some people believe that the current status of the technology is comparable with that of the emerging wind energy development in the 1980s. However, as shown above, given the availability of favourable regulatory regimes, the progress should be much faster than that of wind. However, the most important issue for the technology is to prove itself within the operating environment. There is now an urgent need to have operational experience in the sea. This experience is paramount as it gives confidence to investors, power utilities and governments in the viability of the technology. In addition, technology developers and stakeholders will need to establish a robust supply chain for design and manufacture, transport to site and appropriate installation vessels. The vi-

Country	Policy Name	Year	Comments
Canada	ecoENERGY for Renewable Power	2007	Incentive of CDN 1 c/kWh for up to 10 years
France	Renewable Energy Feed-In Tariff (IV)	2007	
Ireland	Renewable Energy Feed-In Tariff (REFIT)	2005	Fixed price for ocean energy (wave and tidal) is EUR 22 c/kWh.
Korea (Rep. of)	> Extension of Renewable Energy Subsidy > Renewables Feed-in Tariff for (Electricity Business Law)	2002 2001	> Compensation for the difference between the base price and the system marginal price > Tidal/ocean: 62.81 KRW/kWh (0.061 USD/kWh)
Portugal	Modified feed-in tariffs for renewables	2007	Demonstration wave power up to 4 MW: EUR 260/MWh; decreasing to EUR 76/MWh for greater than 250 MW
UK	> Marine Renewables Deployment Fund > Renewables Obligation Certificates (ROCs). Scheme extended in November 2008 to 2037.	2005 2002	> Capital grant 25% eligible costs up to GBP 5 million. Revenue support GBP 100/MWh independent of ROCs. > ROCs trade at up to GB£51/ROC. Renewable generators currently awarded 1ROC/MWh. Likely 2009, scheme banded to give wave and tidal 2ROCs/MWh.
USA	Grants for Developing New Energy Technologies	2004	Grants of up to USD 100k for small businesses

Table 2: Selected financial incentives relevant to marine renewables (Source: [59])

ability of the technology will depend, in the long term on operational reliability of the devices, their maintenance and operating costs, permitting and consent for projects, availability of grid infrastructure and most importantly (in the age of the current credit crunch) the availability of finance. There are, however, many drivers that are likely to play a major role in assisting the development and the roll out of tidal stream technology. These initiatives are mostly related to new energy and climate change legislation in many countries, the prevalence of feed-in tariffs in many EU countries, the change in policy in the USA, the requirements for energy security and fulfilling internationally negotiated carbon reductions.

In summary, 2008 is an important milestone for tidal stream energy conversion. We have seen the first deployment of two grid-connected, large-scale pre-commercial devices in the sea, albeit limited to sheltered test sites. Nevertheless, this progress is extremely important for the technology as it has stimulated many activities including joined-up thinking for developing sites with arrays. The change of administration in the USA, and the ambitious funding of USD 15 billion for renewables, may help to awaken other countries to invest in such areas for the creation of jobs and the exploitation of non-fossil fuel sources for electricity production.

Acknowledgments

This report was solicited by IEA-OES and builds on the 2007 IEA-OES report [8]. Many thanks to my colleagues within the Sustainable Energy Research Group, at the University of Southampton, UK, especially to Luke Blunden for his input and for thoroughly reading and amending the data contained within the report. Finally, I also would like to thank the IEA-OES for giving me the opportunity to write this status report on this very important area of ocean energy.

References

1. Egbert, G. D. and R. D. Ray (2003). Semi-diurnal and diurnal tidal dissipation from TOPEX/Poseidon altimetry. *Geophysical Research Letters* 30(17): OCE 9-1 –– 9-4.
2. Wavenet (2003). Results from the work of the European Thematic Network on Wave Energy. T. Pontes et al., European Community. www.wave energy.net/Library/WaveNet%20 Full%20Report(11.1).pdf
3. www.emec.org.uk/national_standards.asp
4. www.equimar.org/
5. www.orkneyharbours.com/emecnotices_detail.asp?ID=58
6. Carbon Trust/Black and Veatch Ltd. *Phase II UK tidal stream energy resource assessment.* Technical Report 107799/D/2200/03, July 2005.
7. Blunden, L. S. and A. S. Bahaj (2007). Effects of tidal energy extraction at Portland Bill, southern UK predicted from a numerical model. *Seventh European Wave and Tidal Energy Conference*, Portugal.
8. www.iea-oceans.org/_fich/6/IEA-OES_Annual_Report_2007.pdf
9. www.marineturbines.com/3/news/article/7/seagen__the_world_s_first_commercial_scale_tidal_energy_turbine_deployed_in_northern_ireland
10. www.berr.gov.uk/files/file18130.pdf
11. www.belfasttelegraph.co.uk/news/environment/trouble-hits-tide-power-turbine-as-the-blades-fly-off-13918762.html
12. www.marineturbines.com/3/news/article/14/seagen_enters_final_stage_of_commissioning
13. www.openhydro.com/news/OpenHydroPR-270508.pdf
14. energiesdelamer.blogspot.com/2008/03/evenement-sabella-de-la-simulation-la.html
15. www.oceanflowenergy.com/news-details.aspx?id=6
16. lesbonner.mycouncillor.org.uk/2008/10/01/home-could-soon-be-powered-by-the-river-humber
17. www.cleancurrent.com/technology/rrproject.htm
18. www.atlantisresourcescorporation.com/technology
19. www.scotrenewables.com/news.html
20. www.washingtonpost.com/wp-dyn/content/article/2008/09/19/AR2008091903729.html?sub=AR
21. www.tocardo.com/?Tocardo
22. www.pembrokeshirecoastalforum.org.uk/documents/STDAVIDSCOASTALSURGERYwrite-up.doc
23. www.marineturbines.com/18/projects/20/the_skerries
24. www.hammerfeststrom.com/content/view/57/82/lang,en
25. www.openhydro.com/news/OpenHydroPR-211008.pdf (EDF)
26. www.atlantisresourcescorporation.com/news-press/atlantis-seeks-tidal-power-partner-for-pentland-firth-project
27. www.oreg.ca/docs/BC_Tidal_07_10_25.pdf
28. www.openhydro.com/news/OpenHydroPR-150107.pdf (canada)
29. www.cleancurrent.com/media/pressreleasefundy.htm
30. www.lunarenergy.co.uk/newsDetail.php?id=14
31. social.tidaltoday.com/content/sihwa-lake-tidal-power-plant-targets-completion-late-2009
32. Jo, C. H. (2008). Recent Development of Ocean Energy in Korea. Tenth World Renewable Energy Congress, Glasgow, Elsevier.
33. www.marineturbines.com/3/news/article/15/tidal_power_in_the_pentland_firth___yes_we_can_/
34. wales.gov.uk/topics/environmentcountryside/energy/severntidal/?lang=en
35. www.openhydro.com/news/OpenHydroPR-201108.pdf (alderney)
36. J. Clarke, G. Connor, A. Grant, C. Johnstone and S. Ordonez-Sanchez (2008). Contra-rotating Marine Current Turbines: Performance in Field Trials and Power Train Developments.

Proceedings World Renewable Energy Congress (WREC X), Glasgow, UK, 19-25 July 2008.
37. www.energy.soton.ac.uk/index.html
38. Masters I., Chapman J. and Orme J. (2008). A Three-Dimensional Tidal Stream Turbine Hydrodynamic Performance Model. *Proceedings World Renewable Energy Congress* (WREC X), Glasgow, UK, 19-25 July 2008.
39. Alidadi M., Nabavi Y. and Calisal S. (2008). The effect of ducting on the performance of a vertical axis tidal turbine. *Proceedings 27th International Conference on Offshore Mechanics and Arctic Engineering* (OMAE 2008), Estoril, Portugal, 15-20 June 2008.
40. A. Mason-Jones, T. O'Doherty, D.M. O'Doherty, P.S. Evans, C.F.Wooldridge (2008). Characterisation of a HATT using CFD and ADCP site data. *Proceedings World Renewable Energy Congress (WREC X)*, Glasgow, UK, 19-25 July 2008.
41. Baltazar J. and Falçao de Campos J. A. C. (2008). Hydrodynamic Analysis of a Horizontal Axis Marine Current Turbine With a Boundary Element Methods. *Proceedings 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2008)*, Estoril, Portugal, 15-20 June 2008.
42. Maganga F., Pinon G., Germain G. and Rivoalen E. (2008). Numerical simulation of the wake of marine current turbines with a particle method. *Proceedings World Renewable Energy Congress (WREC X)*, Glasgow, UK, 19-25 July 2008.
43. T. McCombes, A. Grant, C. Johnstone (2008). Unsteady Hydrodynamic Modelling of Rotor Systems Used in Marine Current Turbines. *Proceedings World Renewable Energy Congress (WREC X)*, Glasgow, UK, 19-25 July 2008.
44. Myers L.E. and Bahaj A.S. (2008) Scale reproduction of the flow field for tidal energy converters. *Proceedings World Renewable Energy Congress (WREC X)*, Glasgow, UK, 19-25 July 2008.
45. Myers L.E., Bahaj A.S., Germain G. and Giles J. (2008). Flow boundary interaction effects for marine current energy conversion devices. *Proceedings World Renewable Energy Congress (WREC X)*, Glasgow, UK, 19-25 July 2008, pp 711-716.
46. Harrison M.E., Batten W.M., Blunden L.S., Myers L.E. and Bahaj A.S. (2008). Comparisons of a large tidal turbine array using the boundary layer and field wake interaction models. *Proceedings Second International Conference on Ocean Energy (ICOE 2008)*, Brest, France, 15-17 October 2008.
47. Garrett, C. and P. Cummins (2007). The efficiency of a turbine in a tidal channel. *Journal of Fluid Mechanics* 588(-1): 243-251.
48. L. J. Dillon and D. K. Woolf (2008). GIS Mapping of Currents and Constraining Factors for a Major Tidal Stream Resource; The Pentland Firth, Scotland. *Proceedings World Renewable Energy Congress (WREC X)*, Glasgow, UK, 19-25 July 2008.
49. Blunden L.S., Batten W.M.J. and Bahaj A.S. (2008). Comparing energy yields from fixed and yawing horizontal axis marine current turbines in the English channel. *Proceedings 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2008)*, Estoril, Portugal, 15-20 June 2008.
50. Blunden L.S. and Bahaj A.S. (2008). Flow through large arrays of tidal energy converters: is there an analogy with depth limited flow through vegetation? *Proceedings World Renewable Energy Congress (WREC X)*, Glasgow, UK, 19-25 July 2008, pp 1091-1096.
51. Department for Business, Enterprise and Regulatory Reform (2008). Assessment of performance for tidal energy conversion systems. URN 08/1317. www.berr.gov.uk/files/file47400.pdf
52. Department for Business, Enterprise and Regulatory Reform (2008). *Tidal-current Energy Device Development and Evaluation Protocol*. URN 08/1317. www.berr.gov.uk/files/file48401.pdf
53. EMEC (2008) assessment of tidal energy resource. Version 3. www.emec.org.uk/pdf/standards/TRA_draft%203_rev1.pdf
54. www.bsi-global.com/en/Standards-and-Publications/Committee-Members/Committee-member-news/Summer-2007/New-Committee-IECTC-114-Marine-Energy/
55. www.wiki.ed.ac.uk/display/EquiMarwiki/EquiMar
56. www.thecrownestate.co.uk/newscontent/92-round-1-pentland-firth.htm
57. www.mfa.gov.uk/environment/energy/documents/Wave-Tidal_Consenting-guidance.pdf
58. www.publications.parliament.uk/pa/cm200708/cmhansrd/cm081126/text/81126w0152.htm
59. www.iea.org/textbase/pm/?mode=weo.

Ocean Thermal Energy Conversion (OTEC) and Derivative Technologies: Status of Development and Prospects

Gérard C. Nihous
Hawaii Natural Energy Institute, University of Hawaii, 1680 East-West Road, Honolulu, Hawaii, 96822, USA, nihous@hawaii.edu

Introduction

Ever since Georges Claude conducted his pioneering work on Ocean Thermal Energy Conversion (OTEC) nearly 80 years ago [1, 2], generations of engineers have dreamt of tapping this enormous renewable resource. Considerable work was initiated after the oil price shocks of the 1970s, but these efforts waned within the following two decades under less favourable political and economic conditions. In the meantime, OTEC advocates and researchers realised that the ocean thermal gradient could be used not only to produce electricity, but also in derivative technologies like desalination, cooling and aquaculture. These other deep ocean water applications (DOWA) were often envisioned as co-products that could help OTEC break its economic glass ceiling. In time, they would follow their own separate development paths.

A good synopsis of OTEC economics was published in 1992 by Luis Vega [3], who had been instrumental in the execution of some of the most significant OTEC field demonstration projects ever conducted [4, 5]. The emphasis on economics in his brief article certainly was not meant to belittle other challenges faced by OTEC promoters, of which he was well aware, but it does reflect a fundamental need for very heavy financing. Given the sharp rise in the cost of primary energy over the past few years and a renewed interest in renewable energies, it is timely to examine the current status of development of OTEC and its derivative technologies. This summary will include a brief discussion of prospects, technological or other issues, and activities.

OTEC

Long-term opportunities

The OTEC resource covers an area exceeding 100 million km^2 across tropical oceans. Unlike most renewable energy conversion systems, OTEC could deliver power at very high capacity factors and offer baseload capabilities. The overall sustainable size of the resource is limited by the rate of formation of deep cold seawater, although unrealistically high estimates based on solar fluxes are often suggested. Orders of magnitude between 3 and 10 TW appear likely, i.e. a range approximately ranging from twice today's overall electricity consumption to about half of today's primary energy needs [6-8]. The lower bound reflects a possible degradation of the local thermal gradient under very intensive OTEC scenarios.

Favourable OTEC regions are for the most part far offshore from any land. This suggests that a substantial development of OTEC would necessitate floating systems rather than land-based plants. In either case, tropical locations with steep bathymetries remain the best candidates. They include countless small islands as well as some large, sometimes heavily populated island nations (Indonesia, the Philippines, Papua New Guinea, Taiwan). Brazil has extensive coastlines with excellent ocean thermal gradients, while the Gulf of Mexico could provide the USA with good opportunities.

Any significant OTEC development is not likely a) to take place where logistical difficulties are excessive (e.g. lack of infrastructure) and b) to be spearheaded by countries that may have difficulty bearing the risk and burden associated with novel capital-intensive technologies. In a more distant future, a systematic development of remote OTEC regions would probably require the manufacture of energy vectors such as liquid fuels rather than direct power transmission to shore.

Issues

In the standard formulation of OTEC, electricity would be produced by circulating a working fluid through a Rankine thermodynamic cycle. Because of the moderate temperatures involved, ordinary refrigerants such as ammonia typically have been considered for such systems. Available seawater temperature differences T, of the order of 20ºC, must be used not only to define the boundaries of the cycle (evaporation and condensation temperatures), but also to maintain adequate temperature differentials between seawater streams and working fluid as heat is transferred. Hence, the Carnot efficiency of OTEC cycles is based on a fraction of T, and is at most a few percent. All issues related to – and hurdles impeding the development of – OTEC stem from this fact.

OTEC systems require cold seawater flow rates of about 2.5 to 3 m^3/s per net megawatt, with usually greater warm surface seawater flow rates. Large and efficient heat exchangers are thus necessary. Because of a need to also minimise seawater pumping losses, very large conduits also must be envisioned. The Cold Water Pipe (CWP) in particular represents a technological frontier, at least for OTEC plant designs beyond 10 MW [9]. Difficulties with the OTEC power block have been tackled differently. To be able to replace costly metal heat exchangers with simple hardware, Claude invented the Open-Cycle (OC-OTEC) [1] where steam generated from surface seawater in a low-pressure chamber continuously provides the working fluid. Unfortunately, the benefits gained with simpler robust evaporator and condenser designs are offset by the needs for very large low-pressure turbines and multistage vacuum compression systems. This would effectively limit OC-OTEC to plants smaller than 10 MW.

More recently, there have been efforts to improve the low efficiency of OTEC Rankine cycles by using a mixture of ammonia and water through the heat exchangers. This concept is embodied in the Kalina and Uehara cycles. The behavior of the mixture during evaporation and condensation differs from that of pure fluids. It theoretically allows a better match of heat loads during heat transfer since the temperatures of working fluid and seawater can remain closer. A plant based on this cycle requires additional hardware, i.e., a separator before the turbine inlet and an absorber after the turbine outlet. Also, the heat carried by the water in the mixture can be partly recuperated through a regenerator. The Kalina cycle reportedly can boost the Carnot efficiency of an OTEC system by 50% or so, but it also imposes increased demands on the evaporator and condenser. Hence, the viability of OTEC cycles departing from the standard Rankine cycle probably hinges on the availability of better heat exchangers [10].

The greatest technological (and credibility) challenges facing OTEC remain in the realm of ocean engineering, as OTEC field experimentation critically depends on whether a CWP can be deployed and how long it survives. From Claude's hardships in the 1930s [1, 2] to recent trouble in Indian waters [11], the history of OTEC development is rife with CWP failures. The state-of-the-art for operating deep cold seawater pipelines consists of seafloor-mounted high density polyethylene (HDPE) conduits. The largest to date (1.4 m in diameter and 2.8 km long) was deployed off the west coast of Hawaii to a depth of 900 m in 2001 [12]. While HDPE CWPs would be ideal for small megawatt-class systems, OTEC plants of much greater capacity would have to rely on other choices. On the other hand, the exploitation of vast remote offshore areas with floating platforms poses specific challenges that are not addressed with land-based systems.

The most ambitious programme designed to resolve ocean engineering problems specific to large floating OTEC plants remains the comprehensive effort led by the US National Oceanic and Atmospheric Administration (NOAA) in the late 1970s and early 1980s. This included the development of computer simulation tools, model basin tests of potential platforms and pipes, and an at-sea test of a 120 m long, 2.5 m diameter CWP suspended from a small barge. (The pipeline was to be much longer for a representative 1/3 scale test; the actual length reflects funding limitations marking the end of political support for OTEC in the United States after the 1980 presidential election. The pipe was made of two layers of fibreglass-reinforced plastic (FRP) separated by syntactic foam. Manufactured in Washington State, it was shipped to Hawaii in 24 m sections. A field experiment took place for three weeks in the spring of 1983 off of Honolulu.

The large size of OTEC components and the demands imposed by offshore environments on equipment survival and power production logistics result in high projected capital costs. From an economic point of view, this is exacerbated by relatively low power outputs so that standard analyses based on the levelised cost of electricity generation have consistently resulted in uneconomical projects. Even though the cost-effectiveness gap between OTEC and the most expensive fossil-fuel power generation technologies (e.g., oil) has steadily declined, OTEC market penetration has not yet succeeded. When considering estimates of capital costs per unit power as a function of rated power, OTEC systems exhibit a considerable expected economy of scale as one would move from small pilot plants to larger commercial units. Because of a lack of experimental and operational data in running OTEC systems, however, taking advantage of this purported economy of scale has not been possible. Various strategies aimed at leveraging market resources have been attempted. A common approach has been to identify niche markets where the local cost of electricity is sufficiently high and the overall power demand sufficiently low to make OTEC potentially attractive at the modest power outputs suitable for first-generation projects (e.g. 1 to 10 MW). In the best scenarios, a Power Purchase Agreement (PPA), perhaps indexed on a high Avoided Energy Cost (AEC), may be secured with a local utility. While addressing the demand-side aspect of the problem, a favourable PPA has proved insufficient to persuade investors that the risk associated with OTEC is acceptable, with capital outlays as high as USD 300 million for power outputs of the order of 10 MW. Hence, it remains likely that any meaningful demonstration of scalable OTEC systems will be accomplished with a strong commitment of public funds.

Activities

Recent efforts have shown a widespread interest in reviving OTEC, but remain subject to formidable funding hurdles. Accordingly, a number of partnerships were established this year that seek to leverage the necessary technical and financial means to build OTEC pilot plants. In August, Xenesys Inc. of Japan and Pacific Petroleum Company formed a joint venture for the industrialisation and commercialisation of OTEC in French Polynesia. They are seeking support from local authorities to proceed. In October, a consortium of French industrial and public partners launched the initiative IPANEMA aimed at facilitating the emergence of marine renewable energy technologies. In November, Lockheed-Martin (LM) and the Taiwan Industrial Technology Research Institute (ITRI) pledged to collaborate on a 10-MW plant project in Hawaii. Significant monies have already been committed by LM on initial design and research and development activities, but the completion of the project will necessitate a substantial commitment by the US government.

Seawater Desalination

Long-term opportunities

While fresh water is a valuable commodity worldwide, the future of seawater desalination utilising the ocean temperature gradient is hard to evaluate, either in conjunction with OTEC electricity production, or as a stand-alone technology. In the former case, it depends on the development of OTEC with specific additional constraints (e.g. low vacuum components, water transmission to market). In the latter case, it must compete with other desalination technologies. On the bright side, the temperature differential sufficient to generate steam can be much smaller than for OTEC systems that require a turbine. At this juncture, it is likely that any advance in the development of this technology will hinge on the identification of specific niche markets or on some definite progress in deploying OTEC systems.

Issues

The concept of producing fresh water from seawater streams of different temperatures emerged as a logical consequence of OC-OTEC. In such a cycle, about 0.5% of the warm surface water is converted into steam in a low-pressure vacuum chamber; this steam can be recovered as potable water by condensation as long as a Direct-Contact Condenser (DCC) is avoided. From this basic idea, numerous hybrid cycles were devised to preserve advantages afforded by a DCC in OC-OTEC systems (with the addition of a freshwater-seawater liquid-liquid surface condenser), or by other more general OTEC Rankine cycles (with electricity and desalination modules in series, or in parallel with double heat exchangers). The next conceptual leap was to forego OTEC electricity production altogether. This led to the additional consideration of more typical, though more complex desalination technologies such as Multistage Flash (MSF) distillation or Multiple Effect Desalination (MED). The latter relies on using heat from condensing vapour at a given temperature in order to produce vapour at a lower temperature in a series of vacuum chambers (effects). It was identified to be potentially well suited for low-temperature applications, at least in small systems [13]. In all cases, non-condensable gases released at low pressures need to be continuously removed.

Activities

Ocean thermal gradient desalination on the floating barge Sagar Shakti has been successfully demonstrated in 2007 by India's National Institute of Ocean Technology (NIOT) [14]. The project was designed to produce 1 000 m^3/day by converting about 1% of the pumped surface seawater into steam. It extends NIOT's previous experience with smaller land-based low-temperature thermal desalination plants (e.g. Kavaratti).

Seawater Air Conditioning

Long-term opportunities

Seawater air conditioning (SWAC) is the only technology using a thermal property of the oceanic water column that has reached commercial maturity. It is essentially a land-based technology that relies on a close access to cold water from population centres on shore. Hence, cost effectiveness critically depends on favourable siting. In spite of such limitations, there remain a great many attractive locations to further expand SWAC systems.

Issues

The success of SWAC rests on the direct cooling of A/C fluids with available thermal energy rather than with the mechanical energy expended in typical chillers. It is thermodynamically efficient as long as seawater pumping power requirements remain modest. In practice, available HDPE pipes a few kilometres long are generally adequate.

Activities

Many SWAC systems are currently being considered, e.g. in French Polynesia where existing projects have already proved successful. The largest venture with a marine SWAC system to date is planned for Honolulu, Hawaii by Honolulu Seawater Air Conditioning, LLC. The 25 000 ton (A/C) project will utilise nearly 3 m^3/s of 7ºC deep seawater pumped from a depth of about 530 m via a 1.4 m diameter HDPE conduit. Planners have released their Draft Environmental Impact Statement (EIS) to the US permitting authorities in October and no roadblock is anticipated [15]. At the other end of the scale, 'mini-SWAC' systems based on small pressurised pipes conveying the coolant directly to submerged heat exchangers have recently been suggested to serve the needs of the smallest remote island communities [16].

Seawater Enrichment

Long-term Opportunities

High nutrient concentrations are found in deep seawater. Its use in land-based mariculture operations was spearheaded at the Natural Energy Laboratory of Hawaii Authority (NELHA) in the late 1970s. Many similar facilities have been developed elsewhere since then. The production of high-value nutraceuticals and additives (e.g., spirulina, astaxanthin) and of seafood for local niche markets has typically been targeted. The deep seawater needs of even modest land-based OTEC plants are projected to exceed the needs of land-based mariculture, however, especially if land availability (e.g., for raceways) is limited.

Just as long-term opportunities for OTEC lie offshore, the most tantalising prospects for seawater enrichment are embodied in the concept of Artificial Upwelling (AU). With its high deep cold seawater intensity, OTEC seems ideally suited to be a generating technology for AU. Moreover, OTEC relies on strongly stratified tropical waters where the upper layer tends to be depleted of nutrients. Hence, if large floating OTEC plants are built, it might be possible to adjust the release of the effluents to deliberately produce significant artificial upwellings. The success of this approach hinges on achieving effluent neutral buoyancy well within the photic layer. Different stand-alone AU concepts have also been formulated and partially tested, but their practical viability remains to be established.

Issues

The most obvious strategy to potentially boost the oceanic food chain with OTEC deep seawater effluents is to release them at a shallow depth (without interference with the OTEC warm seawater intake). This would generate a negatively buoyant plume that would entrain ambient water until it stabilises. The process is strongly site specific (e.g., local density stratification, cross currents) and very sensitive to scaling effects. All other things being equal, larger plumes sink to deeper waters but undergo less dilution. Time scales of minutes involved in plume stabilisation are too fast to allow immediate nutrient utilization. Instead, primary production (and subsequent trophic enhancement) would take place in the 'far field', over time scales of days. In Low Nutrient Low Chlorophyll (LNLC) waters, the upper ocean is so depleted in essential nutrients that constraints on plume dilution should be less critical than constraints on stabilisation depth.

The Japanese developed a concept that would make the stabilisation of upwelled water independent of AU scale by pumping both lighter surface seawater and deeper nutrient rich seawater in a prescribed ratio corresponding to neutral buoyancy at a targeted release depth. Successful tests were initiated in Sagami Bay, Japan in the TAKUMI experiment [17, 18]. Simple plumes released from the surface as well as the TAKUMI concept were later analyzed for oligotrophic waters [19]. It was confirmed that TAKUMI represents an optimal limit for desirable AU characteristics. It was also shown that in the presence of deep permanent pycnoclines typical of LNLC oceanic regions, the amount of surface water that would have to be pumped for a prescribed mixing ratio with deep seawater rapidly would make TAKUMI impractical for desirable stabilisation depths. Additional results suggest that the presence of moderate ambient cross currents may dramatically improve the physical behavior of AU for simple plumes, with deep seawater flow rates about an order of magnitude higher for a given combination of neutral-buoyancy depth and dilution.

The high flow rate AU configurations discussed so far rely on hard pipes and powerful pumps. There are low flow rate alternatives that would require minimal or no pumping mechanism and could possibly use soft flexible conduits. In one case, the heaving motion of a buoy induced by surface waves would control a valve in a connected vertical pipe; this would allow the upward flow of seawater within the pipe [20]. In another system, less saline deep water brought inside the pipe slowly warms up; as a result, density differences with the outside water column allow a sustained ('perpetual') upward flow of a few millimeters per second [21]. Slowly upwelled water would be quite stable near the ocean surface and therefore correspond to optimal conditions for enhanced photosynthesis. Aside from specific engineering challenges and issues of survival at sea, the low flow rates associated with these concepts would necessitate the deployment of arrays of considerable extents to be quantitatively significant.

Activities

The most significant endeavour is the sustained operation of TAKUMI since May 2003 in Sagami Bay, Japan, where 100 000 m^3/day of 200 m deep water is stabilised relatively close to the surface. TAKUMI has been organised by MARINO-FORUM 21, a subsidiary of the Fisheries Agency of the Government of Japan. Notable as well, although less successful is an attempt this year to deploy novel wave-driven AU pumps off of Hawaii during the first Ocean Productivity Perturbation Experiment (OPPEX-1) led by the University of Hawaii.

References

1. Claude G. (1930). Power from the tropical seas. *Mech. Eng.*, 52, 1035-1044.
2. Gauthier M. (1991). The pioneer OTEC operation: "La Tunisie". *Club des Argonautes, Newsletter 2*. http://www.clubdesargonautes.org/otec/vol/vol2-1-10.htm
3. Vega L.A., (1992). Economics of Ocean Thermal Energy Conversion (OTEC). Chap. 7, *Ocean Energy Recovery: the State of the Art* (R.J. Seymour ed.), ASCE, New York, 152-181.
4. Vega L.A., Nihous G.C., (1988). At-sea test of the structural response of a large diameter pipe attached to a surface vessel. *Proc. Off. Tech. Conf.*, Houston, USA, Paper 5798, 473-480.
5. Vega L.A., Evans D.E. (1994). Operation of a small open-cycle OTEC experimental facility. *Proc. Oceanology Int. Conf.*, Brighton, U.K., 5(7), 16 p.
6. Cousteau J.Y., Jacquier H. (1981). Énergie des mers: plan-plan les watts. Chap. 9 in *Français, on a volé ta mer* (R. Laffont ed.), ISBN 2221007654, Paris.
7. Nihous G.C., (2005). An order-of-magnitude estimate of Ocean Thermal Energy Conversion resources. *J. Energy Res. Tech.*, 127(4), 328-333.
8. Nihous G.C., (2007). A preliminary assessment of Ocean Thermal Energy Conversion (OTEC) resources. *J. Energy Res. Tech.*, 129(1), 10-17.
9. Brown M.G., Hearn G.E., Langley R.S. (1989). A new design of cold water pipe for use with floating OTEC platforms. *Proc. Oceans '89 Conf.*, 1, 42-47.
10. Kobayashi H., Jitsuhara S., Uehara H., (2001). The present status and features of OTEC and recent aspects of thermal energy conversion technologies. http://www.nmri.go.jp/main/cooperation/ujnr/24ujnr_paper_jpn/Kobayashi.pdf
11. Comptroller and Auditor General of India, (2008). Chap. 7, Report No. CA 3 of 2008, 39-48. http://www.cag.gov.in/html/reports/civil/2008_3SD_CA/chap_7.pdf
12. Daniel T.H., (2001). 55" seawater system CIP project update. NELHA Pipeline, 10, October 2001. http://www.nelha.org/pdf/PLiss10.pdf
13. IFREMER (1987). Seawater desalination plants using ocean thermal gradient. Report DIT/SP/GTM 87.154, March 1987.
14. Everest Transmission (2007). First ever floating barge mounted Low Temperature Thermal Desalination plant by Indian scientists. http://www.everestblowers.com/technical-articles/lttd_2.pdf
15. TEC, Inc. (2008). Honolulu Seawater Air Conditioning Draft Environmental Impact Statement, October 2008, 526 p.
16. Garnier, B. (2008). Downsizing SWAC systems for remote customers, *Proc. 2nd Int. Conf. Ocean Energy 2008*, Brest, France. Also, http://www.deprofundis.com/
17. Ouchi K., Ohmura H., (2004). The design concept and experiment of ocean nutrient enhancer TAKUMI. *Proc. Oceans '04/Techno-Oceans '04 Conf.*, 6 pages.
18. Ouchi K., Otsuka K., Omura H. (2005). Recent advances of ocean nutrient enhancer TAKUMI project. *Proc. 6th ISOPE Ocean Mining Symp.*, Changsha, China, 7-12.
19. Nihous G.C. (2006). Near-field evaluation of Artificial Upwelling concepts for open-ocean oligotrophic conditions. *J. of Marine Env. Eng.*, 8(3), 225-246.
20. Karl D.M., Letelier R.M. (2008). Nitrogen-fixation enhanced carbon sequestration in low nitrate, low chlorophyll seascapes. *Marine Ecology Prog. Series*, 364, 257-268.
21. Maruyama S., Tsubaki K., Taira K., Sakai S. (2004). Artificial upwelling of deep seawater using the perpetual salt fountain for cultivation of ocean desert. *J. Oceanography*, 60(3), 563-568.

Status of Technologies for Harnessing Salinity Power and the Current Osmotic Power Activities

Øystein S. Skråmestø and Stein Erik Skilhagen
Statkraft AS, Lilleakerveien 6, 0216 OSLO, Norway

The power of Osmosis

It has been known for centauries that the mixing of freshwater and seawater releases energy. For example will a river flowing into the salty ocean releases large amounts of energy. The challenge is to utilise this energy, since the energy released from the occurring mixing only gives a very small increase in the local temperature of the water. During the last few decades at least two concepts for converting this energy into electricity instead of heat have been identified. These are Reversed Electro Dialysis and Pressure Retarded Osmosis. With the use of one or both these technologies one might be able to utilise the enormous potential of a new, renewable energy source. On a global basis, this potential represents the production of more than 1 600 TWh of electricity per year.

Reversed Electro dialysis (RED) is a concept using the difference in chemical potential between both solutions as the driving force of the process. The chemical potential difference generates a voltage that use membranes for electrodialysis to produce electrical current. This concept is under development in the Netherlands and there are preparations for the first prototype to be build.

For Pressure Retarded Osmosis (PRO), also known as osmotic power, the released chemical energy is transferred into pressure instead of heat. This was first considered by Prof. Sidney Loeb in the early 1970s, when he designed the world first semi-permeable membrane for use in desalination through reverse osmosis. In osmotic power, one can use the naturally occurring osmosis, which relates to the difference in concentration of salt between two liquid, for example sea water and sweet water. Sea water and sweet water have a strong force towards mixing, and this will occur as long as the pressure difference between the liquids is less than the osmotic pressure difference. For sea water and sweet water this would be in the range of 24 to 26 bars based on the salt concentration of sea water.

In a PRO system, filtered sweet water and sea water are let into the system. Before entering the membrane modules, the sea water is pressurised to approximately half the osmotic pressure, approximately 11 to 14 bars. In the module, sweet water migrates through the membrane and into pressurised seawater. This results in an excess of diluted and pressurised seawater which is then split into two streams. One third is used for power generation in a hydropower turbine, and the remaining part passes through a pressure exchanger in order to pressurise the incoming seawater. The drain from a plant will mainly be diluted seawater that will be led either back to the river mouth or into the sea.

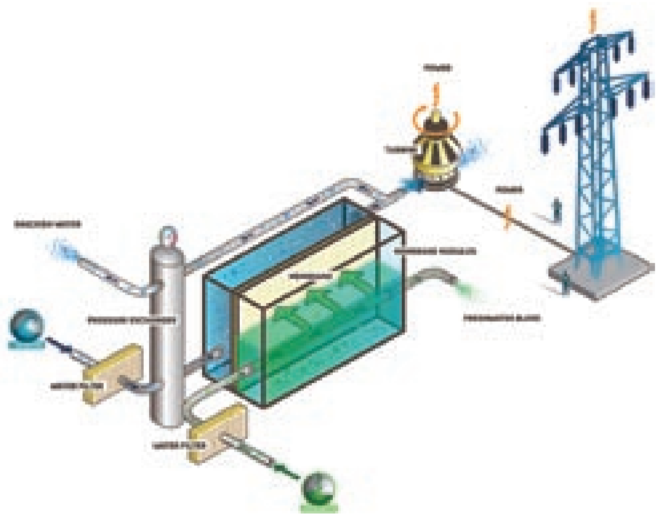


Figure 1. The principle of osmotic power is utilising the entropy of mixing water with different salt gradients. In the process, the water with low salt gradient moves to the side with the higher salt concentration and creates increased pressure due to osmotic forces. Given the sufficient control of the pressure on the salt water side, approximately half the theoretical energy can be transformed to electrical power, meaning that the operating pressure are in the range of 11 to 14 bars enabling the generation of 1 MW per m^3 per sec fresh water.

An osmotic power plant will to a large degree be designed using existing "off the shelf" technology. The two unique components are the pressure exchanger and the membrane. Most efforts in to commercialise osmotic power focus on improving and scaling up these components.

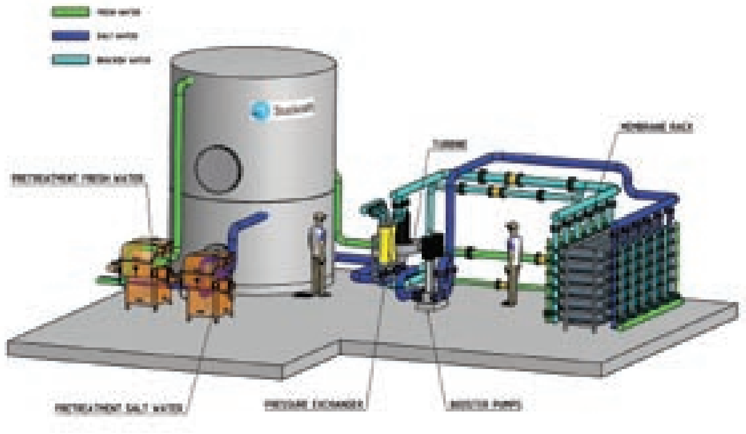


Figure 4. Prototype illustration.

Current Activities

Since the idea of using PRO was developed in the early 1970s, limited effort has been made to bring this technology to a commercial level. There have been some minor studies and testing, but it was not until Statkraft started working with PRO that the development picked up momentum. Since this work started around 1996, research has been focused on designing a suitable membrane for PRO, system design and the feasibility of the concept as a commercial source of energy.

The development of an efficient membrane for osmotic power has been the major focus of the efforts made by Statkraft. The current power density of the membrane is approximately 3 W/m^2, which is up from less than 0.1 W/m^2 a few years back. This research has for most part been done in Germany, Norway and the Netherlands; there are however other groups working on similar topics both in North America and Asia.

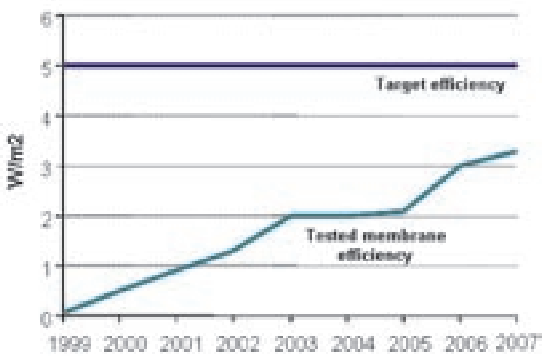


Figure 2. The power efficiency of membranes has been increased from 0.1 to approximately 3 W/m^2.

Figure 3. The prototype at the east coast of Norway.

The world's first prototype of osmotic power is now under construction and the plant will be put into operation in January 2009 in the southeast of Norway.

The main objectives of the prototype are twofold. First, it will confirm whether the designed system can produce power on a reliable 24-hour/day production. Second, the plant will be used for further testing of technology achieved from parallel research activities to substantially increase the efficiency. These activities will mainly focus on membrane modules, pressure exchanger equipment and power generation (turbine and generator). In addition, there will be a focus on further development of control systems, water treatment equipment, and infrastructure with regards to water inlets and outlets.

Environment and Market Potential

Osmotic power's excellent environmental performance and CO_2-free power production will most likely qualify for green certificates and other supportive policy measures for renewable energy. The estimated energy cost is comparable and competitive with the other new renewable energy sources, such as wave, tidal and offshore wind being in the range of 50 to 100 EUR/MWh.

With a potential of more than 1 600 TWh a year world wide, where 170 TWh a year is in Europe, this will likely prove to be a major contribution to the growth of renewable energy, and to represent a new attractive business potential for both the commercial power companies and technology suppliers.

References

1. Thorsen T, Holt T. Semipermeabel membran og fremgangsmåte for tilveiebringelse av elektrisk kraft samt en anordning. Patent No 314575 B, 1 Assigned Statkraft AS.

2. Loeb S. Method and apparatus for generating power utilizing pressure-retarded osmosis, Patent US 4,193,267, Assigned Ben-Gurion University of the Negev, Research and Development Authority, Beersheba, Israel.

3. Markhus E (2006). The Potential for Salinity Power in the World. Norconsult.

Utilisation of Ocean Energy for Producing Drinking Water

Purnima Jalihal and S Kathiroli
National Institute of Ocean Technology Chennai, India
purnima@niot.res.in

Abstract
Wave, thermal gradient and tides are some of the common forms of renewable energies available from the ocean. Even though the understanding on each of these forms has matured over the last few decades, harnessing these ocean energies itself is still in initial stages around the globe. With the growing demand for fresh water around the globe, and ocean being a natural source for water, the need for the desalination of ocean water has attained increasing relevance for present day policy makers. The use of ocean renewable energies to desalinate water presents a viable alternative for the generation of fresh potable water. This paper discusses the efforts made by the National Institute of Ocean Technology, India, towards this goal.

Introduction
The ocean can be huge source of energy in a variety of ways. The most commonly known and studied form is wave energy, followed by ocean thermal energy and ocean currents. Today, renewable energies are being studied extensively due to the slow attrition of natural non-renewable sources. Additionally, the acute drinking water shortage in some countries is making seawater desalination more relevant. If seawater desalination is powered by a renewable energy, the method becomes more viable economically and more environmentally friendly. Using these energies to produce drinking water is an important area of study and research and poses several challenges for implementation.

The use of ocean thermal gradient for power generation has been thoroughly investigated following the works of Claude (1930). A few of the subsequent studies like Kalina (1984) and Uehara (1999) addressed the production of water as a by-product. Apart from a few works that established laboratory-scale models, such as those of the 210 kW rated operational OTEC plant (Vega and Evans, 1994) that worked for five years from 1993 to 98, the research has not progressed to operational plants. One of the main challenges associated with the operationalisation of the OTEC-based power systems was the design of the required system with the added constraint of making the end product economically viable.

The National Institute of Ocean Technology (NIOT) also embarked on the Ocean Thermal Energy Conversion program in early 2000 (Ravindran and Raju Abraham, 2003). The objective was to commission a floating OTEC plant of capacity 1 MW. Though components were realised, due to poor infrastructure and limited ocean installation experience in the country, problems were encountered in the deployment of the large cold water pipeline, due to which the program was suspended. The experience gained has been effectively utilised in putting up the first-ever land-based and floating low temperature thermal desalination plants, which are discussed in a later section.

Presently, NIOT has deployed and recovered several pipelines and small contractors in the country have been groomed to carry out these tasks with ease. Offshore handling equipment and vessels have been procured, which can facilitate offshore operations. Parallel with offshore experience, studies are being carried out on turbines and heat exchangers for furthering OTEC research. India being a tropical country blessed with a large temperature difference between surface and deep sea water, cannot afford to ignore OTEC activities and efforts are on to incorporate a small OTEC plant to power a desalination plant as will be discussed later.

The Indian wave energy plant at Vizhinjam in Kerala was commissioned in the early 1990s. The OWC based plant has been generating power for several years. Several power modules were tested and, in comparison with the common Wells turbine, an impulse turbine was found to give the highest efficiency (Sharmila et. al, 2004). The wave energy generated continuously at this plant was utilised to power a Reverse Osmosis plant to generate fresh water from seawater. This will be discussed in a later section.

Fig. 1. Land-based LTTD plant at Kavaratti, with an inset of the local users.

Fig. 2. Barge-mounted LTTD plant.

Ocean Thermal Gradient-Based Desalination

As mentioned earlier, after the setbacks suffered in the OTEC program, NIOT decided to attempt to utilise the thermal gradient for generating potable water. The low-temperature evaporation of surface water at a reduced pressure generates water vapor and this can be condensed using deep-sea water. This method is called Low Temperature Thermal Desalination (LTTD). After several experiments in the laboratory, NIOT installed the first-ever land-based LTTD plant (Kathiroli and Purnima Jalihal, 2008) at an island in the Lakshadweep islands in western India (shown in Fig. 1). This plant is of a capacity of 100 m^3/day. The bathymetry near the plant is such that the 400 m water depth is available within 500 m from the shore. The plant is located on the shore. A pipe of length 600 m draws 12°C cold water continuously to feed the condenser.

The plant was commissioned in 2005. It has been continuously operating for all these years providing good quality drinking water to the local community. The impact on the life and health of the islanders has been simply remarkable. Along with stomach disorders, various ailments related to dietary salt excess like hypertension, etc., have reduced. The environmental friendliness of the method is very beneficial and attractive in the fragile coral environment. Additionally the deep sea cold water is being used to run the air conditioning system in the entire plant building saving power costs.

The success of the island plant led to the thought of scaling up for mainland requirements. The deep water however is available very far away from the coast; hence, to cater to the mainland, offshore plants become necessary. To demonstrate that an offshore desalination plant is feasible, a barge-mounted LTTD plant of capacity one million litres per day was installed and commissioned about 40 km offshore from Chennai in Southern India.

The first-ever barge-mounted LTTD plant (Kathiroli et. al., 2008) was commissioned successfully, moored in 1 000 m water depth with a single point mooring (shown in Fig. 2). A long, 1 m diameter HDPE pipe was vertically suspended below the barge to draw the cold water. Fresh water of excellent quality was generated for several weeks.

The success of the island LTTD plant has led to the island authorities requesting NIOT to put up more such plants, and work towards commissioning them in mid-2009 is in progress. The success of the offshore plant has led policy makers towards the idea that the technology needs to be scaled up and commercialised. A larger plant of capacity 10 million litres per day is being taken up. This will involve challenges such as design, fabrication and installation of the offshore platform with large cold water pipes. Studies are underway currently.

Wave Powered Desalination

The power generated at the wave energy plant at Vizhinjam was used to drive a Reverse Osmosis (RO)-based plant of capacity 10 000 litres per day. The method involved the use of a special variable speed alternator made indigenously for the Indian Railways. This alternator gave a DC output within a range of speed of the impulse turbine. The power generated was fed to the RO plant (Fig. 3). A battery was also introduced in the circuit for charging when the wave power was high and discharging when it was less. The concept was successful and led to the first-ever wave-powered desalination system. The system generated fresh water out of seawater using the power from the sea. Since studies are being focused towards floating wave-powered devices, application of this system to such a device is yet to be studied.

As mentioned earlier three more LTTD plants are being built in the Lakshadweep islands. In the next phase attempts are being made to put an OTEC module in one of the plants just large enough to power the pumps in the desalination system. Powering the LTTD plant with OTEC will result in 'free' water generation which is season independent and will be a boon to the

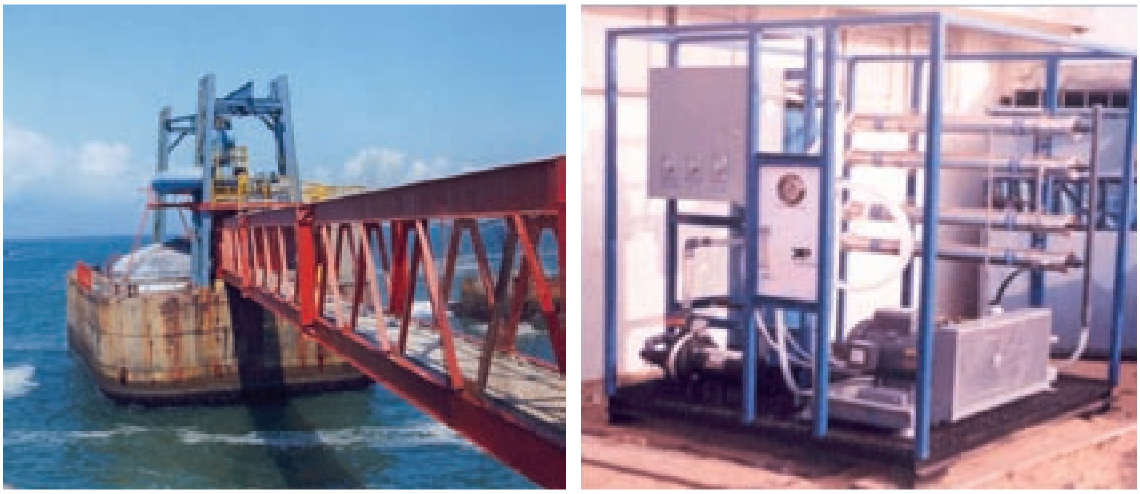


Fig. 3. Wave energy plant and the RO desalination system at Vizhinjam, India.

island communities that depend on diesel generators for power. Currently studies on the working fluid to be used and the design of the turbine for the same are under progress. For the larger capacity LTTD plant, the use of OTEC to generate the fresh water will make the technology really viable since diesel need not be transported from the mainland. The challenge would be to make the turbines and integrate OTEC and LTTD components on a compact offshore platform.

Conclusion

LTTD has been amply understood and fine tuned through the various plants put up by NIOT. The challenge now is to make them self-powered using OTEC and to demonstrate sustainable generation of power and fresh water in the field.

Acknowledgements

The authors are grateful to Dr. S.V.S. Phanikumar for his help in the preparation of this paper.

References

1. Claude G. (1930), Power from the Tropical Seas, *Mechanical Engineering,* Vol. 52, No.12, 19, pp. 1039-1044.

2. Kalina A.L (1984), Combined Cycle System with Novel Bottoming Cycle, *ASME J. of Engineering for Power,* Vol. 106, No. 4, pp 737-742.

3. Kathiroli, S., Purnima Jalihal, and Phanikumar Sistla (2008), Barge Mounted Low Temperature Thermal Desalination Plant, *Proceedings of the Eighteenth International Off-shore and Polar Engineering Conference,* Vancouver, July 2008, pp 518-522.

4. Kathiroli, S., and Purnima Jalihal (2008), Up from the Deep, *Civil Engineering,* V 78, pp 84-89.

5. Ravindran, M., and Raju Abraham (2003), Indian 1 MW Demonstration OTEC Plant and the Development Activities, *Oceans,* V3, pp 1622-1628.

6. Sharmila, N., Purnima Jalihal, Swamy, A. K., and Ravindran, M. (2004), Wave Powered Desalination, *Energy,* V 29, pp 1659-1672.

7. Uehara, H., et al. (1999), The Experimental Research on Ocean Thermal Energy Conversion using the Uehara Cycle, *Proceedings of the International OTEC/DOWA Conference '99,* Imari, Japan, pp. 132-141.

8. Vega, L. A. and Evans, D. E. (1994), Operation of a Small Open Cycle Ocean Thermal Energy Conversion Experimental Facility, *Proceedings: Oceanology International 94,* Brighton, UK.

4. National Activities

In this section an overview of the activities during 2008 and governmental initiatives to implement ocean energy in each IEA-OES country member is provided by the respective delegate. Representatives and national experts from other countries also provided information on their relevant national activities.

Member countries and organisation

PORTUGAL

António F. de O. Falcão, Instituto Superior Técnico

Ocean Energy Policy

A special tariff was established for wave energy in 2007 (Decree-law 225/2007): 260 EUR/MWh for the first 20 MW (decreasing for additional installed capacity).

Legislation published by the Portuguese government (Decree-law 5/2008) establishing a pilot zone off central Portugal. Capacity 250 MW. Area 320 km^2, depth between 30 and 90 m. For prototypes, pre-commercial and commercial plants. A management body is expected to be appointed soon by the government.

A memorandum of understanding was signed in Lisbon, in May 2008, by the US Secretary of Energy and the Portuguese Minister of Economy and Innovation, whose purpose is to establish a framework for the signatories' cooperation on the policy, scientific and technical aspects of wave energy generation.

Research and Development

As in previous years, most of the research and development activity in wave energy has been done at **Instituto Superior Técnico** (**IST**, the School of Engineering of Technical University of Lisbon) in close cooperation with **LNEG-INETI** (a large national laboratory). Cooperation with companies that are developing wave energy technology has been continuing.

Special attention has been devoted at both institutions to modelling, optimisation, control and mooring of heaving (one– and two-body) point-absorbers for offshore deployment. Wave tank model testing is starting in cooperation with University of Porto, whose 28 m by 12 m irregular-wave basin was modified for this purpose. Phase-control of an OWC was experimentally validated in wave flume at IST.

Theoretical, experimental and design work was done at IST on self-rectifying air turbines, with national funding and also within the framework of the European Components for Ocean Renewable Energy Systems project (CORES), in which IST is designing a impulse turbine to equip the one-quarter-scale prototype of BBDB floating OWC plant being tested at Galway Bay, Ireland.

Other areas such as resource assessment, evaluation on constraints related with site location, SIG data bases with relevant information for deployment of wave energy devices have been addressed especially at LNEG-INETI.

IST is a partner in Wavetrain 2, People Initial Training Network Programme of the European Union. Cooperation in wave energy research between IST and Massachusetts Institute of Technology is progressing within the framework of the five-year MIT-Portugal programme funded by the Portuguese government.

Technology Demonstration

The **Wave Energy Centre** (**WavEC**) is a private non-profit association created in 2003 devoted to the development and promotion of wave energy utilisation through technical and strategic support to companies and public bodies. Currently it comprises 15 associates (developing teams, engineering and construction firms, research institutions, project developers and utilities) willing to develop wave energy. Its activity includes technical consultancy, dissemination and technical research and development work; also fields of socio-economics, renewable energy (RE) politics and licensing issues, as well as environmental planning and device monitoring, have been in focus of activities. WavEC leads the environmental work package in the EC-project Equimar-Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact and recently advanced a proposal for the EIA procedure for the Portuguese Pilot Zone, at present being detailed for submission to the management body. WavEC is the coordinator of Wavetrain 2, People Initial Training Network Programme of the European Union. WavEC is further participating in several collaborative research and development projects: Aqua Renewable Energy Technologies (Aqua-RET), Wave Energy Planning and Marketing (WavEPlaM), Components for Ocean Renewable Energy Systems (CORES) and the nationally funded Wave Energy Acoustic Monitoring project (WEAM). WavEC is also responsible for the monitoring and maintenance of the onshore 400 kW Pico OWC power plant in Azores.

EDP, Energias de Portugal, SA has been a pioneer in ocean energy, having invested, some 10 years ago, in the first OWC device at Pico Island (Azores). In the year 2000, the Pico Plant was the first wave energy plant in the world to be grid connected. EDP is presently financing the refurbishment of this plant.

With the "Ondas de Portugal" initiative (OdP), EDP is leading the promotion of a wave energy cluster, in Portugal. Under that umbrella, and in consortium with other Portuguese players, EDP paved the way with the development of the first demonstration, pre-commercial wave farm in the world – the Pelamis. Having assessed a significant number of wave energy devices, EDP is prepared to pursue its "open technology" approach, namely developing other demonstration projects of alternative devices. EDP has a team dedicated to following ocean energy technology, both wave and offshore wind, and is presently part of two consortiums: one, planning the deployment of a deep water wind farm in Portugal, with the WindFloat technology; the other, dedicated to the development of a demonstration project of the Powerbuoy wave energy system.

The world's first wave farm of three Pelamis machines was installed for the Portuguese company **Enersis**, 5 km off the Atlantic coastline of northern Portugal (substation at Aguçadoura) with an installed capacity of 2.25 MW (3 x 750 kW). The wave farm was officially opened on the 23 September 2008 by the Portuguese Minister of the Economy. This technology is developed by Pelamis Wave Power (formerly Ocean Power Delivery).

Kymaner is a small company working in consultancy and engineering of wave energy conversion systems. Presently Kymaner is carrying out, under contract with EDP, extensive rehabilitation work on the Pico OWC plant. Kymaner will supply the impulse air turbine to the quarter-scale floating OWC being tested in Galway Bay (Ireland). Kymaner was invited to submit a proposal for the supply (jointly with the Portuguese company **EFACEC**) of the mechanical and electrical equipment for a 1 MW wave energy plant in Chile.

Martifer Energia, a company within the Martifer Group (large manufacturers of metal structures, also heavily involved in energy), have been developing, mostly in house, their own wave energy technology. The Martifer Energia WEC project is nearing the end of its first phase. During 2008, the research and development team has been optimising all systems ready for installation. In the beginning of the year, a shipbuilding yard was acquired with the construction of their first prototype in mind. The team has been working with D.N.V. (Det Norske Veritas) with respect to the aforementioned systems and also the structure of the actual prototype. The finalisation of the offshore installation process has also been completed so as to minimise the problems in the actual offshore installation, which is of major concern to any potential offshore WEC developer. In-depth finite element (FE) analysis has also been performed on critical areas of the structure so as to reduce possible localised fatigue problem areas.

Tecneira, a promoter in renewables, including wind energy, obtained approval for a 3 MW project in wave energy and is considering deployment at the Portuguese pilot zone and at Peniche (central Portugal). Collaboration and strategic partnerships have been established with promoters and technology companies in other countries.

ENEÓLICA Energias Renováveis e Ambiente Ltda promoted the deployment of a half-scale prototype of the WaveRoller wave energy converter equipped with a hydraulic power take-off system (PTO). Waveroller is a bottom-hinged converter suitable for shallow waters. A storm with rough seas (Hs > 5 m) caused structure damages. A complete disassembly of the device was done for inspection and data analysis.
The next step in the WaveRoller development is to proceed with detailed hydrodynamic simulations of the wing system. Testing in a wave tank (of the University of Porto) is being prepared by IST on a WaveRoller model including a PTO simulator.
Meanwhile, Lena-Group and AWE companies will be working on the manufacturing of a 300-ton prototype and preparing for the final assembly and foundations.

DENMARK

Kim Nielsen, Ramboll, Denmark

Ocean Energy Policy

Since the termination of the Danish Wave Energy development programme in 2002, there has been no dedicated development policy on ocean energy in Denmark. However, wave energy projects have since been able to obtain support through several support programmes in Denmark.

Research and Development

The interest in developing wave energy technology among developers is growing in Denmark and much work is carried out on private basis. However, Danish support to wave energy in 2008 has been approximately EUR 4 million, which is about 6% of the support for all renewables. In 2008, the largest amount ever was given to a single Danish wave energy project (EUR 3.3 million for Wave Star Energy).

The Utilities PSO support under EnerginetDK supports development of renewable energy in Denmark within a frame of EUR 21 million.

ForskVE further adapted the funding method of rewarding power producing demonstration projects with an additional high tariff that each project can define.

In 2008, the EUR 28 million EUDP support programme was launched under the Energy Agency to support projects going into the pre-commercial phase and reward good business plans.

The funding available from these programmes covers all renewable energies. The Danish Council for Strategic Research and the Danish National Advanced Technology in addition cover non-energy projects.

Million EUR	2008	2009*	2010*
EUDP	28	39	53
The Danish Council for Strategic Research	13	23	40
R&D (PSO) Transmission System Operator	21	21	21
The Danish National Advanced Technology Foundation	1	1	2
Total	63	84	116

**Forecast*

Technology Demonstration

Wave Energy

Floating Power Plant A/S (www.floatingpowerplant.com), Poseidon's Organ Demonstration Project is currently being constructed for off-shore test at Vindeby off-shore wind turbine park, by the coast of Lolland in Denmark. The test system is 37 m wide, 25 m long, 6 m high (to deck) and weighs approximately 200 tons. The test system was built in Nakskov harbor and has been launched September 2008. Dong Energy and private shareholders financially support the project.

Poseidon's Organ in the sea (Floating Power Plant A/S).

Wave Star Energy A/S (www.wavestarenergy.com) continued testing the 24 m long 1:10 scale model in Nissum Bredning until August 2008. The 20 floats on each side of the machine are 1 m in diameter and generate electricity up to about 5.5 kilowatt. The system has been in operation since 2006 and over the two years been 17 000 hours in operation and survived 13 storms.

A shortened version of a half-scale 500-kW unit with only two floats near to a pear in the North Sea is being constructed supported with DDK 4 million of funding from Energinet.DK in 2007. This test unit will be operational in the spring of 2009.

A 500-kW demonstration project of Wave Star to be incorporated in the Horns Rev 160 MW offshore wind farm in 2010 has received support from EUDP of DDK 20 million in 2008. This will be installed in 2010.

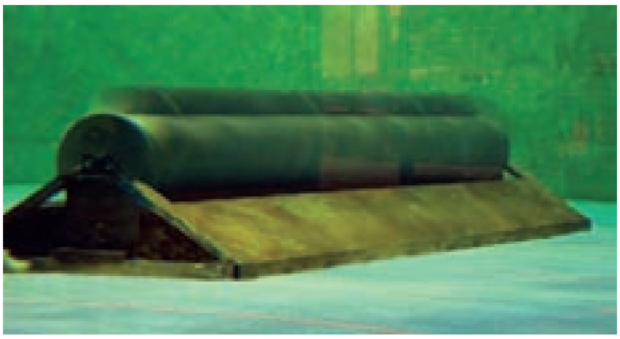
The plan is to sell 100 to 200 500 kW systems before gradually scaling the systems to 2 MW and 4 MW. The ultimate future goal of Wave Star Energy is to produce series of 240-metre long Wave Star machines of 6 MW or even bigger for North Atlantic use.

Wave Star Energy 1:10 demonstration plant in Nissum Bredning and artistic impression of the half-scale 500-kW unit being constructed.

Wave Dragon (www.wavedragon.net/).

Waveplane AS (www.waveplane.com).

The DEXA 7-m model to be placed in Nissum Bredning.



Tideng tidal power project under testing at Sintef in Norway.

Wave Dragon (www.wavedragon.net/), the 237-tonne prototype project in Nissum Bredning, has continued since March 2003. The grid-connected prototype was tested continuously until January 2005. In April 2006, a modified prototype was deployed at a more energetic wave climate in Nissum Bredning and tests are planned to continue with newly secured funding. In beginning of 2009, the Wave Dragon will be re-installed at its original location near the Folkecenter test site.

Wave Dragon plans to deploy a 7 MW Wave Dragon two to three miles off Milford Haven in Wales in the spring of 2010 and test it for three to five years. It plans to install 10 units between 2011 and 2012 in Portugal, for a total of 50 MW. In Wales, 10 additional units will be installed in 2013, for a total of 70 MW.

Waveplane AS (www.waveplane.com) has since 2007 undertaken the development of the Waveplane project in Denmark, financed by private investors. A full-scale prototype of 200 kW has been built in 2008 and is ready for installation in 2009.

Dexa Wave Energy ApS (www.dexa.dk/) has developed a 7-m long model for testing in the same sheltered ocean area as Wave Dragon and Wave Star. The model will be installed in 2008. Following this project, a 15-m long 5-kW demonstration unit is under planning and construction for installation outside Hanstholm in 2009.

LEANCON Wave Energy, is concerned with the development of a floating structure containing a large number of manifolded OWC units. Tests have been carried out at the inverters home, in the open sea and in Aalborg University. The project has received funding from Energinet DK.

Bølgevingen (Wave Wing, www.waveenergyfyn.dk) is a project supported by EnerginetDK for small-scale testing and documentation.

Tidal Power

Despite very low tidal power resources in Denmark, the Danish project Tideng (www.tideng.com) is under development initiated by Bent Hilleke.

The Danish Wave Energy Association (waveenergy.dk/) has also in 2008 hosted its two meetings for national interaction between developers and interested parties.

UNITED KINGDOM

Alan Morgan, Department of Energy and Climate Change (DECC)

Ocean Energy Policy

Renewable Energy Strategy Consultation

The UK launched its Renewable Energy Strategy consultation on 26 June 2008, which ran for three months. The consultation sought views on how to drive up the use of renewable energy (including Marine technologies) in the UK, as part of the UK's overall strategy for tackling climate change and to meet its share of the EU target to source 20% of the EU's energy from renewable sources by 2020.

Responses to this consultation will help shape the UK Renewable Energy Strategy which will be published in Summer 2009.

Renewables Obligation

The Renewables Obligation (RO) is the UK Government's main support mechanism for the expansion of emerging technologies in renewable electricity generation in the UK. Introduced in 2002, the RO obliges electricity suppliers to source a rising percentage of electricity from renewable sources. Suppliers can meet their obligation by presenting renewable obligation certificates (ROCs); by paying a buyout price; or a combination of both. ROCs are issued to renewable generators for each 1 MWh of eligible electricity generated. Generators can then sell these ROCs with or without the electricity to suppliers and so providing them with a premium for their electricity.

The **Energy Act 2008** introduces banding by technology of the Renewables Obligation. This will improve the effectiveness of the RO and provide better support to emerging technologies with wave and tidal technologies each receiving 2 ROCs/MWh of eligible generation. When combined with the extension of the Renewables Obligation from 2027 to "at least 2037", it will maintain stability and significantly increase investor confidence in the UK market.

The Marine Bill

The Marine Bill seeks to address all users of the marine environment to ensure a sustainable approach to the use of the sea. Its main aims are to streamline the consenting process; address the possible need for an overarching body with responsibility for the marine environment; and undertake an evaluation as to the necessity of marine spatial planning.

Marine spatial planning is seen as a tool that gives certainty to all users of the sea. It can lay down areas that address specific conservation, fishing, navigation and development needs. By highlighting these areas, users have a much better idea of where they can or can't use the sea.

Severn Tidal Power Feasibility Study

The UK government is currently carrying out a study looking at the feasibility of a tidal power scheme in the Severn Estuary. The study aims to decide (in the context of the UK's energy and climate change goals and the alternative options for achieving these) whether the government could support a scheme and if so on what terms.

The feasibility study (which focuses on tidal range schemes including barrages, lagoons and other technologies) has two phases, with a decision point and consultation at the end of each. The first phase is focussing on high level issues and short-listing of tidal power options (it is currently considering 10 potential schemes). Subject to a decision to continue, the second phase will consider the costs, impacts and benefits of short-listed options in more detail. The study is expected to conclude in 2010 with public consultation to inform the decision on whether to proceed, the terms of proceeding, and what option (if any) to prefer.

Revised Environmental Impact Assessment (EIA) guidance

Work has started on developing revised EIA guidance for offshore renewables. The new guide will include a section on wave and tidal devices and cover topics such as seascape and visual impact assessment and seal tagging. It will also develop an environmental guidance methodology tool to consider both the positive and negative environmental impacts of a development from construction through to decommissioning. This revised EIA guidance is expected to be published late spring/early summer 2009.

Devolved Administrations

- Wales

The Welsh Assembly government's ***Renewable Energy Route Map***, published in February 2008 (new.wales.gov.uk/consultations/closed/envandcouncloscons/renewenergymap/?lang=en) focuses on how Wales might exploit its renewable energy resources. The map sets out specific actions on how Wales could meet a renewable electricity self-sufficiency objective.

In the light of the marine energy opportunities highlighted in the Renewable Energy Route Map, towards the beginning of 2009 Wales will publish for consultation its ***Marine Energy Strategic Plan*** to consider strategically all the marine proposals.

In addition Wales has also commissioned background studies that will lead to a more detailed ***Welsh Marine Energy Framework,*** which will enable Wales to more accurately determine its optimum and sustainable marine energy targets. The aim is to improve understanding of the marine resource in Wales and its potential for the development against the background of a better understanding of Wales' marine ecosystems. This work is also expected to underpin a formal Wales marine strategic environmental assessment.

- Northern Ireland

Northern Ireland has significant tidal stream resource, particularly off its north coast, and harnessing this resource is an important element of the Department of Enterprise and Investment's (DETI) ongoing work to increase the use of renewables.

DETI has appointed Faber Maunsell/Metoc to undertake a Strategic Environmental Assessment (SEA) of offshore wind and marine renewable energy in Northern Ireland waters. This will enable DETI to work with the Crown Estate, as owner of the seabed, to issue a competitive call for private sector investors to develop commercial projects in certain offshore sites. The SEA, including the consultation phases, will be completed by spring 2010.

- Scotland

In its recent consultation on banding the Renewable Obligation (Scotland), the Scottish government proposed higher support levels for wave and tidal power in Scottish waters (and not in receipt of statutory grants) under the Renewables Obligation mechanism.

The Scottish government continues to invest in infrastructure at European Marine Energy Centre (EMEC) in Orkney.
The Scottish government announced its Saltire Prize in April 2008, and confirmed the details of the challenge in December 2008. This international prize of GBP 10 million, is aimed at inspiring significant technological advances in the marine renewables sector. Further information can be found on www.scotland.gov.uk/Topics/Business-Industry/Energy/saltire-prize.

Research and Development

The UK government continues to support research and development of marine technologies from fundamental research (the SuperGen Marine programme) right through to pre-commercial deployment (Marine Renewable Deployment Fund).

The Energy Technologies Institute (ETI) is a public/private partnership whose focus, small size and wide "reach" aims to bring together the knowledge and skills to create and implement practical solutions to energy problems.

The ETI was created to accelerate the development and commercial deployment of a focused portfolio of energy technologies that will increase energy efficiency, reduce greenhouse gas emissions and help to achieve energy and climate change goals. Established in December 2007, the ETI launched its first call for expressions of interest (EoIs) that month. Marine and offshore wind projects were the first to be targeted.

Typically, the ETI selects a small number of large projects that will demonstrate full system-level solutions; the ETI helps companies form consortia that will have all the expertise required to deliver the project and take it to eventual commercial deployment. The ETI can support and fund up to 100% of the project costs.

The ETI is expected to announce in early 2009 the successful bidders from its first call for expressions of interest.

The proposed "Wave Hub" infrastructure project off the North Cornwall coast has been delayed until spring 2010. When installed, the "Wave Hub" will provide a 20 MW capacity electrical grid connection point 15 km offshore into which wave energy projects can be connected.

The European Marine Energy Centre (EMEC) has established a wave test site (2004) and a tidal test site (2007) and is planning to expand both facilities incrementally to match demand. Contracts have been signed for the deployment of devices at both sites and preparation works for them are underway.

A number of guideline documents for the marine energy sector have been produced, facilitated by EMEC and supported jointly by the UK and Scottish governments. The route to enable adoption of these documents as pre-cursors to becoming standards has been established, with the British Standards Institution (BSI) providing the secretariat. A number of the documents have now been published with further information available at www.emec.org.uk/national_standards.asp.

The Wales Low Carbon Research Institute will be working with other specialist research-commercialisation initiatives to ensure an integrated, best value approach. These include the Energy and Environment Technium in Pembrokeshire and the Sustainable Technium at Baglan Port Talbot. The Energy and Environment Technium, with its strong relationship to the IBM sponsored climate change activities, is expected to link with large-scale tidal stream and wave energy projects.

Current projects at the research and development stages in Wales include the following:

SeaGen Wales Ltd is proposing to develop a 10.5MW tidal energy farm off the coast of the Welsh island of Anglesey in a fast-flowing patch of 25-m deep open sea known as The Skerries. Subject to successful planning consent and financing, the tidal farm could be commissioned as early as 2011. Studies are now underway and will last throughout 2008, with a consent application likely to be submitted in mid-2009.

E.ON and Lunar Energy are proposing to develop a pre-commercial tidal stream project off the coast of Pembrokeshire, West Wales. The proposed scheme will use four to eight Rotech Tidal Turbines (RTT) and will generate up to 8 MW of renewable electricity.

Tidal Energy Ltd's DeltaStream device is a nominal 1 MW unit which sits on the seabed without the need for a positive anchoring system, generating electricity from three separate horizontal axis turbines mounted on a common frame. The technology has been validated in sea trials and simulations by Cardiff University and is undergoing detailed design work at Cranfield University supported by Carbon Connections UK Limited.

Technology Demonstration

EMEC

A number of wave and tidal device prototypes are expected to be installed at EMEC over the coming 12 to 24 months. Advanced installation works are underway for Aquamarine Power's Oyster device and site preparation works are underway for receipt of OPT's Powerbuoy.

OpenHydro has tested, and continues to test, several turbines on the test rig established in the Fall of Warness, off the island of Eday, including the first generation of power to the grid in the UK in May 2008.

OpenHydro has successfully tested the deployment of its vessel and new base structure.

Pelamis

Pelamis Wave Power (PWP) successfully launched the world's first commercial wave farm off the coast of Portugal on 23 September 2008. The three Pelamis wave devices have an installed capacity of 2.25 MW, enough to provide electricity for just over 1 500 households. The electricity generated by the three Pelamis devices will be carried by undersea cable to a substation in Aguçadoura, which will then feed the power into the Portuguese national grid. The three wave devices are controlled remotely by PWP's main office in Edinburgh.

Wavegen

Wavegen shoreline turbine (refurbished with a Scottish government grant) remains operational on Islay on west coast of Scotland.

Application has been made for consent from the Scottish government currently for deployment of 10 Wavegen turbines off Isle of Lewis.

Marine Current Turbine Ltd

The 1.2-MW Marine Current Turbine (MCT) project (known as "SeaGen") started generating renewable electricity in July 2008 in Strangford Lough. It was the world's first commercial-scale tidal system to be connected to a local grid and, when fully commissioned, will generate clean electricity for 1 000 homes.

SeaGen is a twin-turbine system mounted on a monopole. Each turbine has a generating capacity of 0.6 MW and will be powered by the tidal flows in the Lough. The electricity produced is exported to the Northern Ireland electricity grid at Strangford through a cable that has been tunnelled underneath the Lough. In December 2008, MCT announced that, as part of the commissioning process, the device had achieved its fully rated output of 1.2 MW in operation.

JAPAN

Yasuyuki Ikegami, Institute of Ocean Energy, Saga University

Ocean Energy Policy

In order to promote utilisation and development of ocean and preservation of the marine environment, The Basic Act on Ocean Policy, was promulgated in April 2007 and it was made effective in July 2007 by the Japanese government. Based on this law, in March 2008, the Cabinet had established the Basic Plan on Ocean Policy, which would be the guideline of ocean policy for five years starting from 2008. The plan includes 12 government measures, including development and commercialisation of submarine resources such as methane hydrate and polymetallic sulphides. Concerning wave-power generation and tidal-power generation as natural energy, the plan states that "While grasping international trends including those in countries where such generation has been put into practice, basic research for improving efficiency and economic potential should be promoted with due consideration to special features of seas around Japan..". Based on this Basic Plan on Ocean Policy, the Plan for the Development of Marine Energy and Mineral Resources (provisional title) is scheduled to establish within FY2008.

To estimate the outlook for technological movements related to ocean energy caused by enforcement of the Act, the New Energy and Industrial Technology Development Organization (NEDO) conducted a survey regarding present utilising technology of ocean energy and future issues.

In Japan, ocean energy is not included in the sources of new energy listed in the Law Concerning Special Measures to Promote the Use of New Energy (New Energy Law). As a result, financial assistance for promoting practical use and diffusion of ocean energy is not available.

IRELAND

Eoin Sweeney, Ocean Energy Development Unit

Ocean Energy Policy

In 2006, the Marine Institute and Sustainable Energy Ireland prepared the National Strategy for Ocean Energy. This phased strategy aims (a) to introduce ocean energy into the renewables portfolio in Ireland and (b) to develop an ocean energy sector. It aims to support national developers of wave energy devices through concept validation, model design optimisation and scale-model testing and deployment.

- In Phase 1 (2005-2007), an offshore test site for 1/4-scale prototypes was developed in Galway Bay, research capability was enhanced. and some funding was provided from a variety of sources to researchers and developers.
- Phase 2 (2008-2010) continues activities of Phase 1 and provides enhanced support for the demonstration of pre-commercial single devices, This phase provides a mechanism to bring successful designs from the prototype stage to the construction of a fully operational pre-commercial wave energy converter that will supply power directly to the electricity network. The results of this phase will be used to assess the commercial viability of the technology and the resulting industrial opportunities available to Ireland. A grid-connected test site will be developed during the period 2008-2010.
- Phase 3 (2011-2015) will involve pre-commercial small-array testing and evaluation over a sustained period.
- Phase 4 (2016–) will involve development of strategies for commercial deployment of wave power technologies.

The strategic context of the programme has now changed, with targets for the use of ocean energy in Ireland, as announced by the government in the White Paper and the Programme for Government, increased to 75 MW by 2012 and 500 MW by 2020.

To achieve these objectives, the government has provided a three-year (2008-2010) financial package of about EUR 27 million, to be administered by a new Ocean Energy Development Unit (OEDU).

In 2008, the financial allocations are as follows:
- Support for Device Developers (EUR 2 million)
- Enhancement of the test facilities at the Hydraulics and Maritime Research Centre, UCC (EUR 1 million)
- Development of grid-connected Test facilities (EUR 2 million)
- Operation of the OEDU (EUR 0.3 million)

The support package includes a buy-in tariff of EUR 0.22 per KWh for electricity produced from wave and tidal devices.
Other initiatives being taken include the undertaking of a Strategic Environmental Assessment for ocean energy, in all Irish waters, covering offshore wind, wave and tidal. In parallel, the OEDU intends to devise a streamlined system for licensing ocean energy developments.

Research and Development

A research and development funding scheme for industry-led projects in the field of wave and tidal technology has been launched. This covers:
- Industry-led projects to develop and test wave and tidal energy capture devices and systems
- Independent monitoring of projects/technologies
- Industry-led research and development aimed at the integration of ocean energy into the electricity market and the national electricity grid (and network)
- Data monitoring, forecasting, communications and control of ocean energy systems
- Specific industry-led research projects which will be carried out by research centres, third level institutions and centres of excellence with a high level of expertise in the relevant area

The preliminary outline of the scheme, for which a call for expressions of interest is open, is:

Work Type		Feasibility	Research and Development			Prototype
Stage		Concept	Validation Model	Lab Design Model	Process Model	Prototype
Industry Project		up to 45%	up to 45%	up to 45%	up to 45%	up to 40%
Collaboration Project	**3rd Level**	up to 75%	up to 75%	up to 75%	up to 75%	N/A
	Industry	up to 45%	up to 45%	up to 45%	up to 45%	N/A
Typical Duration		2 months	4 months	4 months	12 months	12 – 18 months
Indicative Funding		<€15,000	€30,000 – €45,000	€50,000 – €100,000	100,000 – €250,000	Indicative €1,000,000
Examples of Work type undertaken		Desk study Patent / Paper search	Numerical model Small scale testing	Medium scale test Survival Moorings	Real Ocean testing Motions Control	Full Scale testing Grid connection Control Optimisation
Assessment			Expert Review		Review and Negotiation	

Other relevant research and development information is as provided in 2007:

- Hydraulics and Maritime Research Centre in University College Cork is a key ocean energy research facility in Ireland with special interest in ocean energy research and coastal engineering. The group expanded its staff size in 2007 following the allocation of long term third level research funds.
- University of Limerick has been actively pursuing the development of air turbines for use with oscillating water column devices. It has also secured long-term funding under the Parsons Award scheme and intends to pursue ocean energy research activities.
- The Electricity Research Centre in University College Dublin has had significant involvement in the integration and the study of management issues for intermittent renewable generators, such as wind power systems operating on the national grid. Their interests include modelling of dynamic response of electrical generators and tidal energy systems.

At this point, there is no significant change to the research and development figures reported for 2007. It is anticipated, however, that significant further investments will be made before the end of 2008. Over 20 companies have submitted expressions of interest and 50% of these are being invited to proceed to full proposal stage.

RD&D investment in Ocean Energy Since 2000

	RD&D investment	
	Private sector investment	Public investment
2000	0	0
2001	0	40,000
2002	62,188	146,563
2003	53,308	57,000
2004	81,098	218,228
2005	273,324	387,966
2006	472,732	468,701
2007	505,928	488,055
2008	2,000,000(est)	1,000,000

Technology Demonstration

Open Hydro

The Open Hydro tidal turbine is owned and developed by an Irish company based in Dublin with manufacturing facilities in Greenore, Co. Louth. The Open-Centre Turbine's simple design means that it can withstand harsh ocean tides, while having no impact on marine mammals since it has no oils that can leak, no exposed blade tips and a significant opening at its centre. A grid-connected turbine is currently being tested at the European Marine Energy Centre (EMEC) in the Orkney Islands. The company developed a purpose-built installation barge, which was used for the second-generation device recently deployed. Testing of the turbine is ongoing at EMEC. The company has won two commercial contracts to build devices in the Channel Islands and Canada.

Ocean Energy Buoy

The Ocean Energy Buoy (OE Buoy) is a floating oscillating water column device that generates power from compressed air, which is created with each passing wave. The OE Buoy was optimised at 1:50 scale in HMRC before being tested at 1:15 scale in a large wave tank in Nantes. The current

1:4 scale machine was first installed in Galway Bay in December 2006 where maximum wave heights reached 8 m during the winter period. The machine was successfully tested from December 2006 through to the summer of 2007 without a turbine in order to give comparison with previous tank test work. In September 2007, the OE Buoy was fitted with an air turbine and returned to test where it is continuing to perform successfully.

Wavebob

The Wavebob is a point absorber device. The Wavebob has been tested at 1:50 and 1:20 scale before a decision to build a 1:4 scale machine was taken. A large-scale prototype was installed in Galway Bay in 2006. The developers have an ongoing test programme at the test site. Some testing work was conducted in 2007, with a further round planned for Galway Bay throughout 2008.

Approximately seven further devices are at various stages of research, development and demonstration.

EUROPEAN COMMISSION

Thierry Langlois d'Estaintot, European Commission

EU renewables energy policy context

Renewable sources of energy – wind power, solar power (thermal and photovoltaic), hydro-electric power, tidal power, geothermal energy and biomass – are an essential alternative to fossil fuels. Using these sources helps not only to reduce greenhouse gas emissions from energy generation and consumption but also to reduce the European Union's (EU) dependence on imports of fossil fuels (in particular oil and gas). In order to reach the ambitious target of a 20% share of energy from renewable sources in the overall energy mix, the EU plans to focus efforts on the electricity, heating and cooling sectors and on biofuels. In transport, which is almost exclusively dependent on oil, the European Commission hopes to increase the current target of a 5.75% share of biofuels in overall fuel consumption by 2010 to a 10% share by 2020.

Research and innovation in energy technology are therefore vital in meeting the EU's ambition to reduce greenhouse gas emissions by 60% to 80% by 2050.

However, actions to develop new energy technologies, lower their costs and bring them to the market must be better organised and more efficiently carried out. This is why the European Commission has proposed the Strategic Energy Technology Plan, a comprehensive plan to establish a new energy research agenda for Europe. This Plan is to be accompanied by better use of and increases in resources, both financial and human, to accelerate the development and deployment of low-carbon technologies of the future.

The new approach focuses on more joint planning, making better use of the potential of the European Research and Innovation area, and fully exploiting the possibilities opened up by the Internal Market. In particular, the Plan includes the commitment to set up a series of new priority European Industrial Initiatives focusing on the development of technologies for which working at Community level will add most value. The Plan proposes the strengthening of the industrial research and innovation by aligning

European, national and industrial activities; it also proposes the creation of a European Energy Research Alliance to ensure much greater cooperation among energy research organisations as well as improved planning and foresight at European level for energy infrastructure and systems.

More information is included in the SET Plan document, available at:
ec.europa.eu/energy/technology/set_plan/set_plan_en.htm .

Following the extensive public consultation that ended in June 2008, the European Commission released on 13 November 2008 a communication entitled Offshore Wind Energy: Action Needed to Deliver on the Energy Policy Objectives for 2020 and Beyond (COM(2008) 768 final).

While this communication addresses specifically the actions needed for a large deployment of offshore wind, many of the challenges and initiatives presented are also of relevance for other EU offshore renewable energy resources, such as tidal, wave, thermal and marine current energy. These offshore energy resources, although less developed than wind energy, are also emerging and will be able to contribute to the goals of Europe's energy policy.

In this context, the scope for synergy between Europe's energy policy and the new EU integrated maritime policy is wide and is likely to increase in the future. The fundamentals of both policies are the same: both aim for an integration of economic development and environmental protection. If joined up, they will allow a better exploration of the geopolitical value of Europe's oceans and seas for energy security, competitiveness and sustainability.

The full package, as well as further information on maritime affairs, can be found at ec.europa.eu/maritimeaffairs/subpage_mpa_en.html.

Ocean Energy Support under the Seventh Framework Programme 2007-2013 (FP7)

The first call for proposals of the Seventh Framework Programme (FP7) was launched in December 2006 and included three different topics for ocean energy: New components and concepts for ocean energy converters; A strategy for ocean energy; and Pre-normative research for ocean energy. A second call (FP7-ENERGY-2009-1) was launched in 2008 to cover cross-cutting topics aiming at maximising synergies between wind and ocean energy sectors.

The proposals have to address the following two subject areas:

- **Deep off-shore multi-purpose renewable energy conversion platforms for wind/ ocean energy conversion**
  Content/Scope: Deep offshore renewable electricity generation will raise new challenges in maritime planning and permitting in Europe and in the sustainable development of Europe's marine resources. Offshore renewable electricity generation has certain advantages, such as no competition for land use, higher and more predictable wind speeds and higher ocean power levels. However, costs for deep offshore projects are understandably higher than for onshore or other developments, so research and economies of scale are needed to bring them down to a more competitive level. Research on multiple uses of the sea at the same location shall be carried out: in particular, deep offshore floating multi-purpose renewable energy production platforms able to host wind/ ocean energy converters shall be investigated. The project shall address, inter alia, new

platform design, component engineering, risk assessment, spatial planning, platform-related grid connection and possible use of off-shore renewable energy conversion platforms also for non-energy purposes such as environmental measurements.
Funding scheme: Collaborative project
Expected impact: Improve the cost/benefit ratio of the off-shore technologies through multiple use of the infrastructures. This will bring off-shore renewable energy applications closer to the market.
Other Information: The effective involvement of industrial partners active in off-shore developments is essential to achieve the full impact of the project. This will be considered in the evaluation.

- **Coordination action on off-shore renewable energy conversion platforms**
  Content/scope: The project shall focus on establishing the state of research, technological development and demonstration activities on off-shore renewable energy conversion platforms and on the definition of strategic priorities, including socio-economics aspects, for the development of off-shore renewable energy conversion.
  Funding scheme: Coordination and support action (coordinating action)
  Expected impact: Improved information exchange and promotion of specific research cooperation in this field between academia and industry, public and private actors.
  Other Information: Up to one project may be funded. The review of relevant activities outside the EU, alongside the EU review will be welcomed. Because of the need to have results in time to inform future research policy, the maximum duration of the project is considered to be 18 months. The effective involvement of industrial partners active in offshore developments is essential to achieve the full impact of the project. This will be considered in the evaluation.

The related projects should start by the end of 2009.

Undergoing Ocean Energy Projects Supported by the EC

During 2008, a number of ocean energy projects were still running with the support of the Sixth Framework Programme (FP6). In addition, following the first call for proposals of the Seventh Framework Programme (FP7) in December 2006, two new projects (CORES, EQUIMAR) covering the topics, New Components and Concepts for Ocean Energy Converters and Pre-normative Research for Ocean Energy were negotiated in 2007 and started in 2008.

Two Directorate-Generals of the European Commission are charged with management and monitoring these projects: the Directorate-General for Research (DG Research) for projects with medium– to long-term impact, and the Directorate-General for Transport and Energy (DG TREN) for demonstration projects.

Framework Programme	Number of Projects	Total Eligible Cost	Total EC Contribution
		(M€)	(M€)
FP2 (JOULE I)	2	0.52	0.52
FP3 (JOULE II)	8	6.36	3.05
FP4 (JOULE III)	11	12.14	6.91
FP5	4	7.47	4.54
FP6	4	26.1	7.3
FP7*	2	9.9	7.5
Total	**31**	**62.49**	**29.82**

* First Call 2007 only

Table: European Community funding to ocean energy projects between 1990 and 2008

The table below provides a summary of the ocean energy research projects funded by the European Commission in 2008:

Project Acronym	Duration (Months)	EC Funding for the Whole Duration
WAVE DRAGON MW	36	2.431.000 €
SEEWEC	42	2.299.755 €
WAVE SSG	30	1.000.000 €
CORES	36	3.449.588 €
EQUIMAR	36	3.990.024 €

Furthermore, six new demonstration projects are currently in the starting phase and one additional project supports strategic activities of the recently established European Ocean Energy Association. The total funding allocated to the Association is EUR 10 million.

Following the 2008 call for proposals for demonstration projects in the field of ocean energy, 16 project proposals were submitted. In these proposals 128 organisations from 25 member states and associated states were involved. The projects that will receive financial support will start implementation by the end of 2009.

The Intelligent Energy Europe programme provides funding for the WAVEPLAM (WAVe Energy PLanning and Marketing) project, for a period of 36 months.

European Commission Contacts:

DG RESEARCH
Thierry LANGLOIS d'ESTAINTOT
European Commission
Office CDMA 5/138
B-1049 Brussels Belgium
Tel. direct: +32-2-295.07.65
Fax: +32-2-299.49.91
Email: thierry.d'estaintot@cec.eu.int

DG TREN
Alexandros KOTRONAROS
European Commission
Office DM24 3/115
B-1049 Brussels Belgium
Tel. direct: +32-2-296.00.60
Fax: +32-2-296.62.61
Email: alexandros.kotronaros@cec.eu.int

CANADA

Melanie Nadeau, Natural Resources Canada, CANMET Energy Technology Centre

Ocean Energy Policy

In November 2008, the government of Canada announced that it would reduce its total greenhouse gas emissions by 20 percent by 2020 and also proposed to work with the provincial governments to develop and implement a North America-wide cap and trade system for GHGs. The objective set by the government will require that Canada's electricity needs be provided by non-emitting sources of energy by 2020. This did not result in direct ocean energy policy; however, it emphasised the need to develop inherent resources into a cleaner energy supply for the country.

In April 2008, the federal Programme for Energy Research and Development allocated funding over the next three years to support ocean energy research and development conducted in Canada by federal and provincial governments, in partnership with industry and academia. The initial focus of the programme will be on resource characterisation, technology development including standards, environmental impacts and mitigation and support for research networks. By way of these initiatives, a Canadian ssubcommittee was formed to support the development of international standards for marine energy converters. In the fall 2008, Sustainable Development Technology Canada (SDTC) announced more than CAD 6 million in funding for in-stream current demonstration projects in the St. Lawrence River, Ontario, and the Bay of Fundy, Nova Scotia.

The government of Canada continues to work on the regulatory framework for the management of offshore renewable energy resources (including ocean energy) in areas under federal jurisdiction. This framework is intended to provide an effective and efficient regulatory environment for future ocean energy projects.

Provincially, the province of Nova Scotia (NS) has committed to tidal energy research by funding a Strategic Environmental Assessment (SEA) (released in early 2008), creating a policy framework for developers, and inviting developers to demonstrate in-stream tidal devices through a common demonstration facility in Minas Channel. The NS policy framework entails a collaborative effort between the provincial and federal governments to ensure that the regulatory process for offshore renewable energy demonstration projects is coordinated, efficient and streamlined. A One-Window Standing Committee has been established to carry this forward.

In New Brunswick, the Department of Natural Resources has worked with provincial and federal regulatory agencies to develop an interim policy to provide guidance and direction to Department of Natural Resources staff and the public concerning dispositions of submerged Crown lands for the purpose of research to support the future development of tidal power generation in the Bay of Fundy. Currently interim Crown leases have been awarded to Irving Oil, in partnership with the Huntsman Marine Science Centre. Eleven Crown land sites of 25 hectares each have been offered for up to two years for the research. Primary objectives for the research include assessing the economic viability and environmental impact of tidal power turbines at the sites. Environmental studies will include collection of information on the natural environment, tidal patterns, climatic conditions and behaviour of aquatic life. The sites include the Head Harbour Passage and Western Passage areas of Passamaquoddy Bay, the Cape Enrage area near Chignecto Bay, and the Cape Spencer area near Saint John.

On November 19, 2008, New Brunswick released a Strategic Environmental Assessment of In-Stream Tidal Energy Generation Development in New Brunswick's Bay of Fundy Coastal Waters. The government of New Brunswick is working on a formal response to the report's 19 recommendations that will be released in the coming weeks.

Research and Development

A recent report issued by Natural Resources Canada, Review of Marine Energy Technologies and Canada's R&D Capacity, confirms that Canada is currently well positioned to provide research and development within its existing R&D facilities or as part of demonstration projects. From the concept phase, developers have several facilities that are readily available to test pilot-scale devices, given that the Institute for Ocean Technologies (IOT) and Canadian Hydraulics Centre (CHC) offer some of the best testing tanks and flume tanks in North America. As developers get ready to test devices in the ocean environment, wave energy developers can opt for either Sandy Cove or Lord's Cove of Burin Peninsula, Newfoundland. These are also existing testing sites that offer lower power densities suitable for research activities. Tidal energy developers can turn to the test facility at the

University of Manitoba that is currently grid-testing a tidal current energy device. If a larger-scale resource is required, Canoe Pass and Race Rocks in British Columbia as well as Minas Passage on the east coast are viable resources to test tidal energy devices.

National Research Council – Institute for Ocean Technology

The National Research Council (NRC) Institute for Ocean Technology (IOT) was established in 1985 to provide technical expertise in support of Canada's ocean technology industries. In 2003, IOT officially opened its Ocean Technology Enterprise Centre (OTEC), a facility to assist in the growth and development of new ventures in ocean technology. With a Young Entrepreneurs Programme and an Ocean Technology Co-Location Programme, the Centre helps new and established enterprises to develop their concepts and technologies in a supportive environment, with access to IOT facilities and expertise.

IOT Ice Tank

National Research Council – The Canadian Hydraulics Centre

The Canadian Hydraulics Centre (CHC) has applied research and consulting capabilities on water- and ice-related issues in rivers, lakes, estuaries, oceans and coastal regions. For more than 60 years, CHC has specialised in the application of laboratory studies, numerical modelling, field investigations and engineering analysis to help understand and develop solutions to numerous real-world problems.

Model tests of wave energy converters and in-stream turbines have been undertaken in recent years. In-stream turbines can be tested in a high-discharge flume where both flow turbulence and velocity shear are simulated, so that their effects can be investigated and assessed. Wave energy converters can be tested at large scale in both long-crested and short-crested waves. The combined effects of waves, currents and winds acting together can also be studied.

Multi-directional Wave Basin

In addition, there is substantial expertise within Canada's university sector that can enable the advancement of technologies in Canada. In May 2008, Dalhousie University in Nova Scotia hosted a workshop with academia and research organisations from across the country that aimed to mobilise marine energy interests and establish the Canadian Marine Energy Research Network (C-MER). C-MER will be applying to the National Science and Engineering Research Council (NSERC) for strategic network grants aiming to support their objectives, which include conducting research on technical, environmental, socio-economic, policy and regulatory issues to reduce risk and uncertainty for government and industry stakeholders.

Technology Demonstration

Testing Facilities

▪ Fundy Institute of Tidal Energy

The Fundy Tidal Energy Centre will initially have three underwater berths to connect commercial scale devices to the power grid. The facility, developed by Minas Pulp and Paper, will allow the three developers to share costs, assess and limit potential impacts, and test under similar conditions. The first unit is expected to be operational in 2010. Funding for the facility was awarded by NS Department of Energy and EnCana.

Canadian Technology Advancement

▪ Clean Current Power Inc.
Clean Current is one of the three and the only Canadian company selected to demonstrate in the Bay of Fundy at newly created Fundy Institute of Tidal Energy. The commercial-scale demonstration unit is expected to be operational during the third quarter of 2009. Funding for the commercial project has been awarded by Sustainable Development Technology Canada (SDTC).

▪ New Energy Corp.
New Energy installed and grid-connected a 25-kW EnCurrent Power Generation System at Pointe du Bois, Manitoba, for the University of Manitoba. In addition, it has installed and micro-grid-connected a 5-kW EnCurrent Power Generation System by ABS Alaskan Inc. in Ruby, Alaska, for the Yukon River Inter-Tribal Watershed Council.

▪ Verdant Power Canada
Verdant plans to install a new blade design on existing RITE turbines (demonstrated in the East River of New York City) and has continued plans to complete the Gen5 turbine design. The Cornwall Ontario River Energy Project (CORE) plans for a pilot demonstration in St. Lawrence River are underway. Funding has been awarded by SDTC and Ontario's Innovation Demonstration Fund.

▪ Coastal Hydropower Corp
Coastal Hydropower has completed financial forecasting, and development of variable pitch cross-flow turbine is underway. The company is preparing for demonstration sites identified in Ontario and British Columbia.

▪ Wave Energy Technologies
WET has plans for installing a 40-kW WET EnGen™ at Sandy Cove, Nova Scotia, as a pre-commercial demonstration project.

▪ SyncWave Systems Inc.
SyncWave plans to develop its first-generation demonstration device off the west coast of Vancouver Island, British Columbia. Demonstration targeted for deployment in late 2009-2010.

UNITED STATES OF AMERICA

Alejandro Moreno (US Department of Energy) and Walt Musial (National Renewable Energy Laboratory)

Ocean Energy Policy

2008 saw a continued increase in activity and interest in ocean energy in the United States. In late 2007, the US Department of Energy (DOE) was authorised for the first time to establish a research programme in marine and hydrokinetic energy, including wave, current (tidal, in-stream and ocean), and ocean thermal energy conversion (OTEC). DOE spent USD 10 million on advanced water power research in 2008 (the technologies above plus select conventional hydropower technologies), most of which was spent on ocean energy. Funding levels for 2009 are still uncertain, and a final decision may not be made until after the new president has taken office in January 2009, but current Congressional language indicates an intent to increase spending on marine and hydrokinetic technologies to approximately USD 30 million. The US Navy has continued its support of specific ocean energy projects, including wave, tidal and OTEC, and all ocean energy research has been consolidated under its Naval Facilities Command (NAVFAC). The two US agencies charged with regulating marine and hydrokinetic energy facilities, the Federal Energy Regulatory Commission (FERC) and the Department of the Interior's Minerals Management Service (MMS), have devoted significant resources to improving their understanding of the technologies and their social and environmental effects, and each continues to refine its regulatory processes. Individual states have also continued or begun to pursue ocean energy related projects through a number of organisations, including the Oregon Wave Energy Trust, the West Coast Governors Agreement, and the Pacific NorthWest Economic Region.

The primary focus of federal level activity has been the provision of grants to support companies and institutions active in ocean energy in the United States. Fourteen companies and organisations received over USD 7 million in grants for a diverse and complimentary set of projects covering a wide spectrum of ocean energy technologies. These included five technology development projects (two each in wave and tidal power, and one in OTEC, ranging from site development to subsystem design and testing to full-scale prototype development; assessments of extractable wave and tidal resources in the US; a broad-based cooperation aimed at reducing the time, cost and potential negative impacts of project siting; support of International Electro-technical Commission's (IEC) international ocean energy standards development; and the establishment of two National Marine Renewable Energy Centers. In addition, the DOE is supporting in-kind assistance through its national laboratories (National Renewable Energy Laboratory (NREL) and Sandia National Laboratory (SNL)) to two cooperative research and development projects.

Earlier this year, DOE launched a competitive grant solicitation for ocean-energy device manufacturers under Phase I of the Small Business Innovative Research (SBIR) programme. The total amount that will be allocated is not yet known, but interest in the SBIR programme has so far been very high.

The DOE has also been directed by the US Congress to prepare a report summarising what is currently known about the environmental impacts of marine and hydrokinetic energy. Information has been collected from a wide variety of global sources, and the text has been developed in collaboration with two other US federal agencies, the National Oceanic and Atmospheric Administration (NOAA) and the US Department of the Interior (DoI).

The United States has also begun to take a more active role internationally in the field of marine energy. DOE proposed and will serve as the operating agent for the fourth IEA-OES annex, to investigate the potential environmental impacts of ocean energy. FERC and MMS have agreed to jointly lead the effort. DOE also supports the National Renewable Energy Laboratory to serve as the Secretary to the US Technical Advisory Group (i.e., mirror committee) to the IEC Technical Committee 114 on marine renewable energy standards. The DOE has also undertaken an active effort to identify and characterise device-specific marine energy technologies and projects as they develop, releasing in December a database that provides up-to-date information on wave, current and ocean thermal energy conversion in the USA and around the world.

The fully searchable database catalogues both energy conversion devices and specific projects, and allows the user to search based on a number of criteria including geographical location, resource type and technology stage or project status. Users can easily access details of a device or project's size, dimensions, and mooring methods, as well as project details such as information on permitting, power purchase agreements, partnerships, or even an interactive GPS mapping feature that allows the user to pinpoint project location worldwide (where this data has been made available by the project developer). The database can be accessed at the following website:
www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx .

On the federal level, a number of other departments and agencies are interested in the development of ocean energy. In addition to MMS, FERC, the Navy and the National Oceanic and Atmospheric Administration, these include the US Coast Guard (USCG), the US Fish and Wildlife Service (FWS), the US National Park Service (NPS), the US Army Corps of Engineers (ACOE), and the Environmental Protection Agency (EPA). While each has different mandates and responsibilities, all are actively increasing their capabilities to address the development of ocean energy in the United States, and are collaborating and communicating on a regular basis to help ensure that the industry can continue to move forward in harmony with the concomitant uses and resources of the ocean.

On the state and local levels, ocean energy must be developed in accordance with each state's coastal zone management plan, which can involve participation, input and permission from a number of state government resource and regulatory bodies. Many of these agencies and organisations, along with local government and stakeholders, have become active participants in the proposal, siting and development of offshore energy projects in the United States. Their input is increasingly sought early in the project development process, and their engagement and support has indicated a significant potential to facilitate the siting process.

Despite the demonstrated interest and investment in ocean energy, federal investment and production incentives still trail those of most other renewables. Most forms of ocean energy did become eligible for the renewable energy production tax credit (PTC) for the first time in 2008, but the rate of USD 0.01/kWh is only half of that granted wind, solar and closed-loop biomass generation.

Research and Development

A number of US universities and research organisations are active in ocean energy research and development, and their efforts continue to increase in scope and depth. In 2008, three such universities were named as part of two National Marine Renewable Energy Centers, designed to become integrated research, development and open water testing facilities. Oregon State University and the University of Washington have combined their respective expertise in wave and tidal energy, along with significant oceanographic, hydrodynamic and environmental capabilities to form the Northwest National Marine Renewable Energy Center. The University of Hawaii's Hawaii Natural Energy Institute will lead a second centre, the National Marine Renewable Energy Center in Hawaii, which will focus on research and development, scale and lab testing, and prototype development for wave and ocean thermal energy. Both centres will involve active partnerships with industry, including technology developers and utilities, as well as with other national and international research institutions.

Outside the framework of the centres, other organisations from across the country are devoting ever increasing resources to ocean energy. Florida Atlantic University has established an research and development programme investigating ocean current energy from the Gulf Stream, while in the Northeast, the Universities of Connecticut, Maine, Massachusetts, New Hampshire and Rhode Island all are active in the field. Other universities with interest in ocean energy include the University of Michigan, Maine Maritime Academy, Massachusetts Institute of Technology, Georgia Tech, and Texas A&M. Some utilities have also shown interest in developing renewable energy projects, including Snohomish PUD (Washington State), Pacific Gas and Electric (California) and the Hawaii Electric Company. In the private sector, 30 companies in the USA are currently in the process of researching and/or developing ocean energy devices, split nearly evenly between wave and current, with a few involved in ocean thermal energy.

In 2008, the United States hosted a variety of conferences and workshops aimed at advancing the technology of marine energy. In April 2008, the National Renewable Energy Laboratory (NREL) joined with the Ocean Renewable Energy Coalition (OREC), the Minerals Management Service (MMS) and International Energy Agency-Ocean Energy Systems (IEA-OES) to host and sponsor the first Global

Marine Renewable Energy Conference in New York City, which was held in conjunction with the 14th IEA-OES Executive Committee meeting. OREC promises to continue this conference as an annual event, with the 2009 meeting to be held in Washington, D.C., on 15 and 16 April. EnergyOcean 2008 was held this year in Galveston from 24 to 26 June. The Hydrovision conference held in July 2008 in Sacramento, California, included a symposium devoted to marine and hydrokinetic technologies. Finally, EPRI in co-operation with the Department of Energy held a two-day workshop on the research and development needs of the industry in October 2008.

Technology Demonstration

While relatively few companies in the USA have reached the stage of full-scale deployment and testing, many are moving aggressively towards project development and technology demonstration.

Those that have put hardware in the water in 2008 include:
Verdant Power, which successfully demonstrated its grid-connected multi-unit turbine array of tidal energy (New York, NY) and subsequently filed for a Federal license allowing commercial sale of electricity in the USA.
Resolute Marine Energy (RME), which conducted ocean testing of a prototype wave energy converter that produces compressed air for offshore aquaculture operations. Development work was funded by the National Oceanographic and Atmospheric Administration (NOAA) and RME's project partners were Ocean Farm Technologies and the Massachusetts Institute of Technology.
Ocean Renewable Power Company (ORPC), which demonstrated the technical viability of its Turbine Generator Unit (TGU), the core of ORPC's proprietary Ocean Current Generation (OCGen™) technology, through extensive testing in tidal currents that come from the Bay of Fundy, in Cobscook Bay and Western Passage, near Eastport, Maine.
Ocean Power Technology (OPT), which continues to operate a 40-kW floating point absorber off the Kaneohe Marine Corps Base in Hawaii.

Organisations moving towards the demonstration phase include:
The Snohomish Country (Washington) Public Utility District, which is the process of completing engineering design and obtaining construction approvals for a tidal pilot demonstration plant in the Admiralty Inlet region of the Puget Sound.
Concepts ETI, which is developing an articulated-blade turbine for a floating OceanLinx Oscillating Water Column WEC, to be deployed and tested in Hawaii within two years.
The State of Hawaii, along with a number of industrial partners, which is seeking to site the construction of a 10 MW OTEC demonstration plant in state waters.
Pacific Gas and Electric, the largest investor-owned utility in the USA, which plans to initiate engineering design, conduct baseline environmental studies, and submit all license construction and operation applications required for a tidal energy demonstration plant for the two WaveConnect sites in Northern California.

BELGIUM

Pieter Mathys, Julien De Rouck, Gabriel Michaux

Ocean Energy Policy

Belgium is a federal country, with one federal government and three regional governments.

The offshore environment of the Belgian Continental Shelf and the transmission of energy (70 to 380 kV) are both federal jurisdictions.

The federal legislation of Belgium has a Tradable Green Certificates (TGC) support mechanism for renewable energy, but it does not yet include tidal current or wave energy (Royal Decree of 5 October 2005).

However, the federal legislation does provide a zone where the exploitation of wind, wave and tidal current energy can be exploited. This so called 'Domain Concession' zone is situated some 24 to 57 km offshore (Royal Decrees of 20 December 2000 and 17 May 2004). This zone is situated offshore because of the possible visual hindrance of windmills.

Research and Development

The Belgian Federal Science Policy (BELSPO) has funded a new research project in order to optimise the basic knowledge of offshore energy on the Belgian Continental Shelf.

Currently three Ph.D. projects are running at the Civil Engineering Department of Ghent University.

GERMANY

Jochen Bard, Institut fuer Solare Energieversorgungstechnik, ISET

There is a very strong interest in renewable energies in Germany among the public, as well as in research and industry. This includes a continuing high interest in ocean energy, the available resources of which amount to only a small percentage of the electricity consumption. Consequently, the focus of the interest is more on the technology development rather than the exploitation of the national resources. However, some activities have begun to look at the resources within the German exclusive economic zone, especially in the North Sea, from private as well as public interest. The combination of wave energy installations with offshore wind farms that are to be installed is currently seen as the most attractive option.

Policy and Prospects

The new EU renewable energy directive implements the decision of the European Council of March 2007 to increase the share of renewables in the EU final energy consumption from 8.5% in 2005 to 20% by 2020. All member states are prescribed concrete targets based on the starting situation, existing potential and economic strength. Germany's target is an increase from almost 6% in the reference year 2005 to 18% in 2020. The expansion of renewable energies in Germany is a success story. This is confirmed by a recent report by the federal environment ministry: within the last five years, the share of renewables in the final energy consumption in Germany has doubled to 8.6%. Their share in gross electricity consumption now stands at 14.2%, twice as high as in 2002.

German companies occupy the lead position on the global market for environmental goods. With a share of 16% in the international trade volume and an export volume of EUR 56 billion, in 2006 Germany again ranked at the top of the international trade league, ahead of the United States (15%) and Japan (9%). The macroeconomic benefits of a vigorous expansion of renewable energies are strong. The total turnover from construction and operation of renewable energy systems in Germany in 2007 was approximately EUR 25 billion. The number of people employed in the industry reached the 250 000 mark – equivalent to a 55% increase within three years. Current figures show that renewables already pay off for Germany's national economy: for every euro of funding arising from the Renewable Energy Sources Act, EUR 1.60 is saved on fossil energy imports and prevention of external environmental damage caused by other energy sources. The export figures in the renewable energy sectors have also increased in recent years, for example to around 80% for the wind industry.

The public funding in the framework of the national energy research programme for renewable energies was approximately EUR 100 million in 2007. This programme is open to ocean energy research, but not many proposals have been funded yet.

A feed-in tariff for electricity from wave and tidal energy similar to the tariff for small hydropower (around 7 to 10 cents) is available under the Renewable Energy Act of 2005. This figure will be raised in 2009. A first international conference on ocean energy was held in 2006. A series of national marine energy forums continued in April 2008. In order to coordinate German experts and to exchange information between the different activities such as IEA, IEC and other National activities (DWA), an ocean energy working group was founded in the year 2008. One of the main activities will be to create a Wiki-type ocean energy online knowledge base in German language.

Research and Development

Currently around 15 research and development institutes and universities are involved into developing wave, tidal current and osmosis power in the framework of mainly European research projects. Ocean energy research under the German programme is currently limited to a tidal turbine concept and component development. ISET and LtI are jointly working on the pitch system, the dynamic simulation, control engineering and new drive train concepts for marine current turbines such as the British Seagen concept, which was successfully installed in 2008. The total amount of public funding between 2001 and 2008 was around EUR 2.5 million.

Technology Demonstration and Projects

Currently there is only one German manufacturer of ocean energy devices. In 2005, Voith Siemens Hydro, one of the larger hydropower manufacturers of the world, acquired the Scottish company Wavegen. Under the leadership of Voith, Wavegens' Wells turbine technology has been developed further. This development achieved a mayor milestone in 2008. Now, some first projects are on the way to using this new turbine technology. The most advanced is the installation in the Spanish Mutriku harbour, where construction work is almost completed and installation is scheduled for the beginning of the year 2009. Voith Siemens Hydro is also developing a marine current turbine technology. The concept includes a horizontal rotor with fixed blades and variable speed, using a direct drive generator.

Other German suppliers, such as Bosch Rexroth and Contitech, deliver components and parts for a number of ocean energy devices for wave as well as tidal turbine technologies, mainly in Europe.

In 2008, the German utility RWE created a new operating company for all of its European renewable energy activities, RWE Innogy. The UK subsidiary of this new renewables business, npower renewables, has announced plans to invest in Wavegen's technology as well as MCT's tidal turbines in the UK. The same approach applies to E.ON UK but for different technologies and projects. No installation has been realised in Germany yet and no recent plans for installations have been published.

NORWAY

Peter Hersleth, Statkraft SF

Ocean Energy Policy

Several national programmes and targets exist for renewable energy in Norway, but none are specific for ocean energy. Similarly, there are several government support mechanisms for technology development, prototype and full-scale test devices for renewable energy, but no specific support exists for ocean energy.

Research and Development

The Norwegian university of Science and Technology in Trondheim is involved in several research and development projects relating to wave, including the EU-sponsored SEEWEC project.
Statkraft AS, a state-owned utility, has launched an ocean energy university programme focusing on offshore wind, wave and tidal energy, including three Nordic universities (NTNU, Norway; University of Uppsala, Sweden; and DTU, Denmark). Statkraft has allocated EUR 10 million for a period of four years, and the universities will match the projects financed by the programme to double the effort.

"Wind&Ocean" is a multiclient programme for Norwegian SMEs with international growth ambitions. It is a co-funded programme between Innovation Norway and the participants, and consists of market research, business development and networking opportunities. The main focus is Western Europe and the companies are mainly technology developers in the wave, tidal and wind sectors.

Technology Demonstration

Demonstration project wave power. Tussa Kraft and Vattenfall will deploy two or three 40-kW Seabased technology devices outside Runde on the west coast of Norway in 2008/2009. The devices will be connected to the grid.
Pilot project osmotic power. Statkraft AS is building the world's first osmotic power plant in 2008. The pilot will produce 2 to 4 kW of power and will be ready for testing in 2009.
Hammerfest Strøm tidal prototype project. The nacelle of the grid-connected 300-kW prototype deployed in 2003 has been taken out of the water for verification, and will be reinstalled in 2009.
The Fred Olsen company. Olsen is actively involved in field testing of scaled, energy-producing units based on the point absorber principle and on experiences gained through three years of testing with the research rig "Buldra" and similar installations.
Several other technologies are planning, demonstration and/or pilot projects the coming years: **Pelagic Power AS, Langlee AS, Wave Energy** (Wave) and **Moonfish Power, Hydra Tidal, Tidal Sails** (Tidal).

MEXICO

Gerardo Hiriart, Instituto de Ingeniería UNAM

Ocean Energy Policy

A draft law to promote the use of renewable energies was presented to the Congress (LAFRE).

Research and Development

An amendment to the tax law was presented to create a tax exemption to those using renewable energies and is under discussion.
A law to charge 0.5% tax to energy importers was presented to support research and development in renewable energies.

Technology Demonstration

The Federal Electricity Commission (CFE) is studying with Oceanlinx of Australia a possible joint test of a wave electricity generator.

CFE is studying possible support for a Mexican inventor (Antonio Bautista) for a wave electricity generator fixed to the bottom of the sea.

The National University of Mexico (UNAM) has a project called IMPULSA studying the use of very hot hydrothermal vents in the Gulf of California to generate electricity.

UNAM has built several models of floating hydrogenerator (QK), and has tested them in a simple channel. Plans are to test the QK in a towing tank in the USA.

Dr Steven Czitrom of the Institute of Ocean Research of UNAM has developed a pump activated by the resonance of the waves. Several tests have being made.

SPAIN

Jose Luis Villate, Robotiker Energía, Tecnalia

Ocean Energy Policy

Current legislation regarding ocean energy in Spain was established in 2007 and no other measure for supporting ocean energy has come up in 2008. At this stage, current legislation does not refer to national targets and the Spanish government supports new demonstration plants by setting a specific feed-in tariff for each project, depending on the investment cost of each project. However, it is expected that ocean energy will be included in the future 2011-2020 Renewable Energy Plan, including targets and other supporting measures.

Regional governments from the Basque Country, Cantabria, Asturias, Galicia and the Canary Islands are also promoting the installation of demonstration plants through different ways.

Basque Country and Cantabria governments intend to set up infrastructures on their coasts during next years to test different technologies of wave energy conversion. The Basque test facility will allow full-scale prototype testing and the installation of demonstration and pre-commercial wave power plants up to 20 MW. This infrastructure (Biscay Marine Energy Platform, BIMEP) is expected to be in operation in 2010. Both governments have also stockholding in wave energy projects under construction in their territory, which are mentioned further on.

View of Biscay Marine Energy Platform (BIMEP)

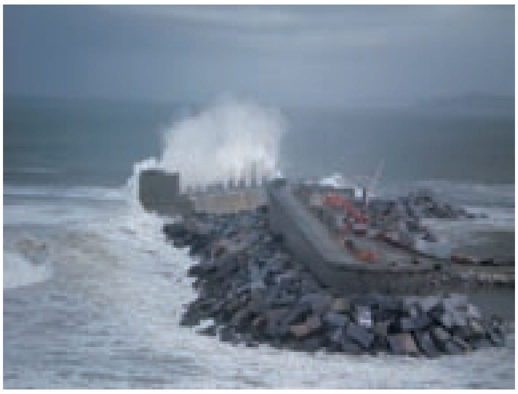
Canary Islands have funded in 2008 the cost of developing a wave energy atlas to promote the installation of wave power plants. Other regional funds for research and development purposes may be granted for development and installation of demonstration plants.

Regarding standardisation issues, AENOR, the Spanish standardisation board, launched a national mirror group for the international committee IEC/TC 114 in June 2008. This group will work on the establishment of standards concerning marine energy, mainly for wave and water currents devices.

Research and Development

Development of some wave technologies has been funded by the Spanish government through general funds of its Research and Development National Plan, though this plan does not include specific funds for ocean technologies.

A highlight among the projects funded through the national plan is a strategic research project for the development of three wave energy converters called PSE-MAR. This important project, coordinated by the Tecnalia technology corporation, is carried out by a consortium formed by the three technology developers (Hidroflot, Pipo Systems and Tecnalia), industrial companies, research and development centres, and universities. In 2008, EUR 3.5 million have been allocated for this project for the period 2008-2010.



Mutriku OWC installation

Another example of research and development projects is Abencis Seapower, a new technological company, that is developing in collaboration with technological centres a new simple and low-cost on-shore technology for electricity production and desalination purposes.

Technology Demonstration

There are no ocean energy plants in operation in Spain to date. However, there are at least two demonstration projects under construction, which are expected to be operational in 2009:

Powerbuoy installed in Santoña, Cantabria

- **EVE (The Basque Energy Board)** is promoting an OWC (Oscillating Water Column) power plant in Mutriku's breakwater. This plant consists of 16 turbines, 18.5 kW each, which result in an estimated power of 296 kW for the whole installation. The approximate cost of the plant is around EUR 5.7 million (including the cost for civil work). The project is partially supported by the European Commission.
- **Iberdrola Energías Marinas de Cantabria S.A** installed at sea in September 2008 the first OPT's Powerbuoy of 40 kW in Santoña, Cantabria, without grid connection. After finishing a testing stage with this buoy and a detailed analysis of investment costs, a second phase could be tackled. This second stage would include the installation and grid connection of nine buoys of 150 kW each. The group that is developing this power plant is owned by Iberdrola Renovables (60%), Total (10%), OPT (10%), IDAE (10%) and SODERCAN (10%). The budget for the first phase, which includes the electrical marine infrastructure, amounts to some EUR 3 million.

Apart from these two projects already under construction, several other companies are studying the installation of wave energy plants in Galicia, Asturias, Cantabria, Basque Country and the Canary Islands.

In June 2008, Iberdrola and Tecnalia announced an agreement to develop the **Oceantec project**, with the goal of putting into operation a high-performance wave energy device at competitive cost. This initiative, which will stimulate industrial development in the Basque Country, will involve a joint investment of around EUR 4.5 million with expectations that the device will be built and tested throughout 2009. The first stage of sea trials started in September 2008 with the commissioning on the Basque coast of a quarter-scale prototype.

Oceantec scale prototype

Abencis Seapower is promoting the installation of a demonstration plan of its new on-shore technology, which it expects to be operational in 2010. Hidroflot has announced the investment of EUR 14 million to install an offshore 1.5-MW wave power plant in Asturias with its multi-buoy platform technology. Norvento and Sea Energy are also studying the promotion of different wave power plants in Galicia. The local government of Tenerife, in collaboration with other Spanish partners, is studying the possibilities of installing wave energy demonstration plants in Tenerife.

ITALY

António Fiorentino, Ponte di Archimede and Gerardo Montanino, Gestore dei Servizi Elettrici

Ocean Energy Policy

Italy's major policy to support the deployment of renewable energies is based on obligatory targets combined with a green certificate trading scheme that has been working since 2001 (introduced by Legislative Decree 79/99). Italian energy suppliers producing or importing more than 100 GWh per year from conventional sources are obliged to ensure that a percentage of their annual electricity supply for the domestic market comes from entitled new renewable energy plants. Sanctions for non-complying liable parties are foreseen in general terms and the energy regulator (AEEG) is responsible to calculate them case by case.

Two main modifications on the legislation promoting renewable energy sources were approved by the government (Financial Law 244/07) at the end of 2007, to go into effect in 2008:

- A revision of the green certificates system (GC)
- The introduction of a feed-in tariff mechanism

Wave and tidal energy producers may choose to benefit from by one of the two support schemes, the only requirement being the capacity of power plant.

Under the current GC system, producers receive 15 years support consisting of tradable Green Certificates, which can be negotiated on the market. The total amount of GCs is allocated among power plants according to their technology maturity. Each megawatt-hour produced is multiplied by a specified ratio before GCs are allocated. For wave and tidal, the ratio is 1.8. The renewable obligation that for 2008 (in relation to the electricity produced or imported during 2007) has been set at 3.8%, and it increases annually by 0.75% until 2012. In 2008, the reference price for the GC market was set, by GSE, at 112.88 EUR/MWh.

The feed-in tariff mechanism grants a guaranteed price per KWh to small installations (capacity under 1 MW) over a 15 years period, differentiated by energy source. In case of wave and tidal energy, each megawatt-hour receives EUR 340. Besides this, the sale of energy provides additional income. The average market price for 2008 was 85 EUR/MWh.

Technology Demonstration

The Kobold turbine is a submerged vertical-axis turbine for exploitation of marine currents installed in the Strait of Messina, 150 m off the coast of Ganzirri, since 2002. The realisation of the Enermar prototype has been financed by Ponte di Archimede Company, together with a 50% fund paid by the Sicilian Region Administration (Regione Siciliana), in the framework of European Union Structural Funds. This project has been disseminated among the developing countries in which UNIDO operates and three first countries that expressed interest were the People's Republic of China, the Philippines and Indonesia. A joint venture was created, under the auspices of UNIDO, between "Ponte di Archimede" and the Indonesian Walinusa Energy Corporation. A location to install the tidal current plant in Indonesia has been identified in the Lomboc Island (immediately at east of Bali).

NEW ZEALAND

John Huckerby, Aotearoa Wave and Tidal Energy Association

Ocean Energy Policy

National Programme

There are no national targets for deployments of marine energy projects. However, the recently published New Zealand Energy Strategy (11 October 2007) sets a target of 90% of generation to come from renewable sources by 2025 (currently approximately 65%).

Public Funding/Governmental Support

The New Zealand government announced the first award of funds from the Marine Energy Deployment Fund (MEDF). The fund aims to promote marine energy by offering NZD 2 million per annum over the next four years for the deployment of prototypes in New Zealand waters. The first award – of NZD 1.85 million – was made to Crest Energy Kaipara Limited to assist in the deployment of three tidal turbines in New Zealand's largest harbour, the Kaipara Harbour. The company plans to deploy up to 200 tidal turbines progressively over 10 years. The grant is subject to environmental planning consents being granted to the project and to the company attracting matching external funding. Consent hearings for this project were held in the same week that the MEDF funding was awarded.

Relevant Legislation

The Emissions Trading Scheme passed into law on 25 August 2008. However, the new National-led coalition government, which was elected on 8 November 2008, has called for a Select Committee investigation into the ETS.

The previous Labour-led coalition government proposed a draft National Policy Statement (NPS) on Renewable Electricity Generation. An NPS provides regional and district territorial authorities with guidance on how to deal with development proposals. Public submissions were called for in November and December 2008 and a board of inquiry will to consider these submissions in early 2009. The final NPS may be enacted by mid-2009.

The National Coastal Policy Statement was enacted in 1994 and has been under statutory review for some time. The Coastal Policy Statement (which has effect in the Coastal Marine Area out to 22 km or 12 nautical miles) may establish new regulations. Legislation for the Exclusive Economic Zone (from 22 km to the edge of the continental shelf) is also under review. Both will have impacts and benefits on marine energy projects.

Planning Consents

Northland Regional Council granted consents to Crest Energy Kaipara Limited and recommended the approval of two further consents to the Minister of Conservation in late August 2008. In early September, four parties, including Crest Energy itself, appealed the consents, requiring a hearing in the Environment Court. Evidence was provided to the court in late 2008 and the hearings have been set down for mid-2009.

Greater Wellington Regional Council granted a non-notified consent to Neptune Power Limited, allowing it to deploy a single 1-MW prototype tidal turbine in Cook Strait. A non-notified consent means that there were no public hearings and the consent was granted essentially to allow environmental monitoring of a single device deployment. Neptune Power has indicated that it intends to deploy the prototype in late 2009.

A third tidal energy project by Energy Pacifica Limited to deploy twenty 1-MW tidal turbines in Tory Channel indicated that it intended to submit resource consent applications before the end of 2008.

Research and Development

The New Zealand government has provided research and development funding to three marine energy projects over last four years. Principal beneficiary is the Wave Energy Technology – New Zealand (WET-NZ) consortium, which comprises two Crown Research Institutes (Industrial Research Limited (IRL) and the National Institute for Water and Atmospheric Research (NIWA)) and a private company, Power Projects Limited.

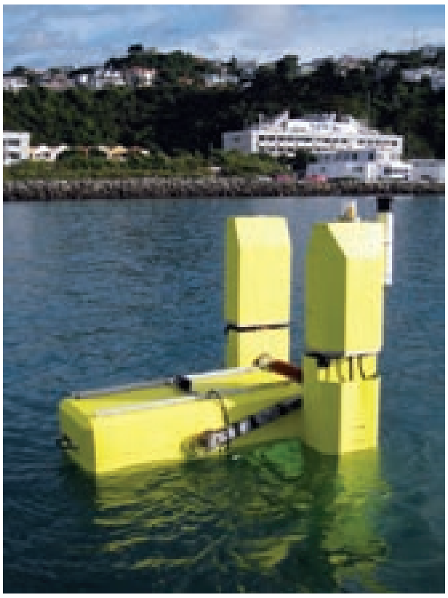


Figure 1. The WET-NZ device in Evans Bay, Wellington, June 2008 (© PPL)

In July 2008 the New Zealand government's research and development funding agency announced that it was going to provide funding for three projects:

- The WET-NZ research and development consortium project will receive six further years of funding to continue development of its wave energy converter.
- NIWA secured funding for a three-year project to study the optimisation of tidal and ocean current systems.
- NIWA also secured funding for a three-year project to review extreme waves and storm surges. Although this is really a natural hazards project, there will be applicability to wave energy projects, particularly with respect to wave device survival.

Technology Demonstration

The first deployment of a wave energy prototype took place in late 2006 but the Wave Energy Technology – New Zealand (WET-NZ) device was redeployed in Wellington Harbour to undergo mooring trials in June 2008 (Figure 1). The WET-NZ consortium has constructed a second 2-kW prototype, which will be deployed in open-ocean conditions in early 2009.

Two other tidal/ocean current projects have indicated that they are planning prototype deployments in 2009.

SWEDEN

Susanna Widstrand, The Swedish Energy Agency (STEM)

Ocean Energy Policy

In Sweden, the governmental support to ocean energy renewable sources producing electricity comes from the electricity certificate system. The electricity certificate system is a market-based support system for electricity from renewable energy sources.

The system came into force on 1 May 2003 and runs to the end of 2030. It is intended to increase the production of renewable electricity and also make the production more cost-efficient. The objective of the electricity certificate system is to increase the production of renewable electricity with 17 TWh by 2016 compared to 2002. The system replaces earlier public grants and subsidy systems. The principle of the system is to provide a market place where sellers and purchasers of certificates can meet.

In Sweden, there is a wave energy test facility called Islandsberg. The research area is situated on the west coast of Sweden, about one nautical mile (2 km) west of the Islandsberg peninsula in the municipality of Lysekil. This site provides an acknowledged good wave climate, access to harbours, other modes of transportation and other necessary facilities. It is close to Uppsala University's Klubban Biological Station, as well as to Kristineberg Marine Research Station, both of which are co-operators in the project. Furthermore, the closeness and the possibility for connection to the main grid was a decisive factor in the choice of the location. The project will be concluded in 2013-2014, after which all the equipment will be removed.

Research and Development

Centre for Ocean Energy

- Timeline: 1 July 2004 to 30 June 2008
- Total budget: EUR 4.67 million
- Funding: The Swedish Energy Agency (STEM) 48%
- Project leader: Prof. Mats Leijon, Uppsala University

The four-year timeline has now passed for the **Centre for Renewable Electrical Conversion (CFE)**. The Centre involved basic research in the areas of wave power, marine current and vertical wind. Several Ph.D. students were working on CFE projects. An evaluation of the CFE has been done by an independent consultant, showing good results as a centre. An application for a new four-year phase of the CFE has just been filed to STEM from the project leader.

Wave energy

Research Facility for Wave Power – Lysekil project part II

- Timeline: 1 June 2006 to 31 December 2009
- Total budget: EUR 4.711 million
- Funding: The Swedish Energy Agency (STEM) 48%
- Project leader: Prof. Mats Leijon, Uppsala University

Figure 1. The new 6-m diameter "doughnut-shaped" buoy at the test facility Islandberg (Photo courtesy of Uppsala University)

The project aim is to study wave power technology under real conditions and to assess the impact from and on the environment. This pilot project consists of ten 10-kW generators, which will be installed between 2006 and 2009 at the test facility Islandberg, with the project continuing until 2014.

Reported project activities 2008:

- Four new buoys were constructed during the early spring of 2008, including a 6-m diameter "doughnut-shaped" buoy (see Figure 1).
- Construction of an under water substation started in late winter of 2007 and was completed during summer 2008.
- The first generator has been at a standstill due to rope breakage. It was restarted with a new steel wire instead and the patented "doughnut-shaped" buoy (see Figure 1), and is still in operation.
- New resistors, with lower resistive values, were installed at the receiving station on Gullholmen Island.
- Two new generators were completed in Uppsala, in summer 2008.
- Inspection dives were completed during June 2008.
- Marine environmental work progressed as planned during spring 2008 and finished for this year in early July.
- An observational (lattice) tower was raised in July 2007 with the help of a helicopter. The tower was equipped with a battery bank, solar panels and a small wind turbine for energy generation. However, a storm during the spring of 2008 destroyed the wind turbine and damaged the tower slightly, resulting in repair work during spring and summer of 2008. The camera system was successfully added to the tower on 4 July, enabling observations directly from Uppsala.

Marine current

Experimental Setup for Kinetic Electric Energy Conversion of Moving Water

- Timeline: 1 January 2006 to 30 September 2007
- Total budget: EUR 0.2 million
- Funding: The Swedish Energy Agency (STEM) 50%
- Project leader: Prof. Mats Leijon, Uppsala University

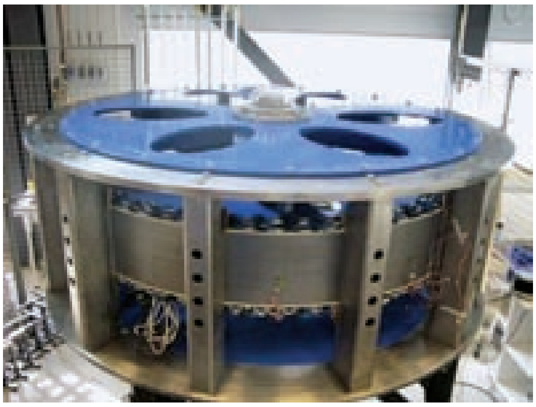


Figure 2. The laboratory experimental set-up of the very slow speed permanent magnet generator (5 kW). (Photo courtesy of Uppsala University.)

An experimental build-up of a very slow speed permanent magnet generator (5 kW) was made (see Figure 2). The generator was cable wound with a 120-pole rotor designed for a nominal speed of 10 rpm. The experimental set-up also included measurement technology.

The generator was tested in the laboratory without a turbine; instead it was powered by an induction motor and connected to a resistive load. The generator has verified the simulations and calculations already presented internationally. The high efficiency at part load and at overload is an essential feature of the generator. The experience gained in building this prototype will also be useful in the future construction of a generator and a turbine for testing in a marine environment. An application for such a build-up of a turbine and generator for marine environment has just been filed to STEM from the project leader.

For more information, see www.el.angstrom.uu.se/meny/eng/index_E.html.

Technology Demonstration

Performance Test of Wave System

- Timeline: 15 December 2007 to 31 December 2009
- Total budget: EUR 2.89 million
- Funding: The Swedish Energy Agency (STEM) 50%
- Project leader: VD Billy Johansson, Seabased AB

The performance test includes manufacturing of prototypes (20 and 50 kW), launch (at the test facilities Islandsberg and EMEC, Orkney, Scotland), connection, start-up and operation. Every step includes measurements to control the performance of components and systems.

Design of the 20-kW units is proceeding well (one unit to be placed off Orkney and three units on the west coast of Sweden) and main parts are selected and ordered. Much equipment has already arrived at the factory in Lysekil. Production started 1 June in Lysekil and some serious delays from subcontractors will hopefully not disturb the finishing of the project in time. Eight people were hired in Lysekil in May 2008 for the production. For the 50-kW unit placed off Orkney, the final design will be done during autumn this year. For the units planned to be placed off Orkney in the test area of EMEC discussions are ongoing about a final contract (EMEC did send a new contract that was changed in December 2007 and it has been commented by Seabased) as well as the period of testing. EMEC is making some changes in their test field and it is not clear yet when the test field can be available again. For the 20-kW units it is still possible to make some changes on the buoys and the foundations but other parameters are fixed as production has started.

For more information, see www.seabased.se/ .

OTHER COUNTRIES

AUSTRALIA
Tom Denniss, Oceanlinx

Ocean Energy Policy
No specific programmes have been implemented in Australia during 2008 for ocean energy, but an expanded programme has aimed at increasing the installed capacity of renewable energy within Australia. Key Australian politicians are aware of ocean energy, and it certainly qualifies for support under the more general renewable energy scheme.

During 2008, the Australian government announced a AUD 500 million Renewable Energy Fund will be fast-tracked, with the aim of disbursing the fund by mid-2010. Funding is to be matched with AUD 2 of private investment for every AUD 1 of government funding.

During 2008, the Australian government announced a target of 20% of energy from renewable sources by 2020. The government is working on implementing a uniform feed-in tariff scheme for renewable energy, as well as a trading emissions scheme, titled the Carbon Pollution Reduction Scheme (see www.climatechange.gov.au/emissionstrading/index.html).

Research and Development
No specific support for research and development activities in ocean energy has been announced during 2008.

Technology Demonstration
The 500-kW Oceanlinx demonstration wave energy project at Port Kembla has been upgraded during the latter part of 2008, and will be re-installed in early 2009, along with full grid interconnection. Other Oceanlinx projects are planned for southern Australia.

Carnegie Corporation has further advanced its technology via their Fremantle (Western Australia) project, and has several other projects planned for other parts of Australia.

Bio Power Systems continues to progress its proposed demonstration projects in Bass Strait via a wave energy facility (King Island) and a tidal energy facility (Flinders Island).

Atlantis Resources Corporation installed a 150-kW tidal device at Phillip Island (south of Melbourne) during 2008.

BRAZIL
Francisco M. Miller, Petrobras

Ocean Energy Policy
No national programme or governmental support specially for ocean energy existed until the end of 2007, when the Ministry of Science and Technology (MCT) has approved a science and technology plan that includes ocean energy as one of its priorities. An initial meeting, sponsored by COPPE and MCT, took place at COPPE on 22 January 2008 as a first effort to establish a national network for ocean energy development.

Due to the change of the Executive Secretary of Ministry of Mines and Energy, the nomination of the Brazilian representatives for IEA-OES has been delayed. These representatives will be named soon.

Research and Development

Research and development activities have been conducted by COPPE / UFRJ (Federal University of Rio de Janeiro), Petrobras and the University of Rio Grande (FURG). A governmental effort is beginning at the sponsorship of Science and Technology Ministry, and participation of other electrical utilities and universities is expected for the next year. A few demonstration projects will start in 2009.

Research and Development Activities

- COPPE / UFRJ has developed a shoreline wave power converter device based on pumping water to a hyperbaric chamber, and producing electricity through a Pelton turbine. This device was tested in small-scale model and simulated for Ceará coast and Rio Grande coast conditions. COPPE is also conducting a redesign study of the tidal barrage of Bacanga river estuary. This barrage was constructed in the 1970s and it was planned to be the first tidal power plant in Brazil, but has never been operational. Now, due to silting of the estuary and deterioration of the barrage, the plant must be redesigned to comply with the actual difference of water level of 2.5 m, instead of the former 7 m.
- PETROBRAS has been developing an ocean energy atlas that will be finished on 2008, studying new devices and prospecting opportunities for demonstration projects in Brazil. A reduced scale model of COPPE's shoreline was tested in the ocean tank, using the wave climate of Rio Grande coast, and the results are now being analysed. A cooperation with FURG (University of Rio Grande) was signed as described below.
- FURG is conducting a simulation of ocean conditions at Rio Grande do Sul coast and a feasibility and environmental study for an offshore installation. An ocean energy workshop took place at Rio Grande, in November 2007, as one of the project activities, with the participation of INETI's researcher Teresa Pontes, IST's researcher Antonio Sarmento, FURG and Petrobras researchers.

Key Institutions

- COPPE / UFRJ: The department of Ocean Engineering of COPPE / UFRJ (Federal University of Rio de Janeiro) has been developing research activities in ocean energy since 2001, taking advantage of its high knowledge in naval and offshore technology. The Submarine Technology Laboratory has developed the hyperbaric wave power device, and studies for other devices have been conducted.
- PETROBRAS / CENPES: CENPES is the biggest research centre in Latin America, and is responsible for all research and development activities for Petrobras. The Renewable Energy Division in CENPES develops projects in solar energy, wind power, hydrogen, biomass, biofuels, energy efficiency and ocean energy. Since 2004, this division has been studying ocean energy.
- FURG (University of Rio Grande): The Institute of Oceanography has been developing research activities on oceanography since 1970 and gives support to the Brazilian Antarctic Base since 1983. This Institute has developed a strong knowledge on oceanography and ocean engineering and it is now starting research and development activities on ocean energy.

Technology Demonstration

Pecém Ocean Energy Project: the aim of this project is to install a 50-kW COPPE prototype at Pecém Port (Ceará coast). It was developed initially by Eletrobras, Ceará the state government and COPPE. It is now being developed by Tractebel (Brazilian branch), the Ceará state government and COPPE.

- Technology: Hydraulic pumping and Pelton turbine
- Size: 50 kW (full scale)
- Name: Usina de Pecém
- Location: Pecém Port, Ceará State
- Developer: COPPE/UFRJ, Eletrobras, Ceará state government
- Current Status: cooperation contract under signature
- Funding: public (Government and Eletrobras, a public utility company)

FRANCE

Michel PAILLARD (Ifremer) with contributions of ADEME (French Agency for the Energy and the Environment), ARER (Regional Energy Agency of the Reunion island), EDF, DCNS, Sabella consortium, Hydro-Gen, Ecole Centrale de Nantes, Satie, IRENAV, Egiseau.

Ocean Energy Policy

The Environment Round Table (« Grenelle de l'Environnement »)
In March 2007, Europe set 2020 targets for reducing greenhouse gases emissions (20%) and an obligation to use renewable energy (20% of final energy consumption). In France, the Environment Round Table ("Grenelle on the Environment") has accepted these objectives. France's Environment Round Table was organised by the Ministry of Ecology, Energy, Sustainable Development and Town and Country Planning (MEEDDAT). The aim of the Environment Round Table is to define the key points of government policy on ecological and sustainable development issues for the coming five years.

For the first time, the Round Table brought all the civilian and public service representatives together around the discussion table. It was also suggested that the French overseas territories became a showcase of renewable energies including a target for some of them, 50% renewables in 2020 and taking measures to reduce energy consumption. To achieve its objectives, the Environment Round Table advocated efforts to expand research and development to prepare for the energy future. This requires a concerted plan to mobilise more mature sectors and efforts to develop promising sectors. The use of all renewable energy sources is relevant in this context, and marine renewables could contribute. In addition to climate change mitigation, the rising cost of energy offers real opportunities to increase the share of renewable marine energy.

Special Funds to Support Demonstrators in Energy Technologies
The Environment Round Table should also accelerate the development of marine renewable energy. Facing the development of ocean energy systems, the French Agency for the Energy and the Environment (ADEME) will host a demonstration fund to support the transition from the research and development activities of developers to the industrial deployment. A call for expressions of interest will be released in 2009. The selected technologies will be defined in a roadmap that would be communicated before.

Ifremer Prospective: Marine Renewable Energies – Prospective Foresight Study for 2030
The ocean is a huge reservoir of renewable energy sources, such as wind, currents, tides, waves, marine biomass, thermal energy and osmotic power. Like other maritime nations in Europe, France enjoys significant potential to develop these energy sources, especially overseas. In March 2007, the chief executive officer of Ifremer launched a prospective

foresight study on these energies for the time horizon of 2030. With support from the Futuribles consulting group, 20 French partners representing the main stakeholders in the sector (MEEDDAT, ADEME, EDF, DCNS, Total, TECHNIP, Grenoble INP and Ecole Centrale de Nantes) carried out this work. Their objective was to identify the technologies, to specify the socio-economic prerequisites for technologies to emerge and be competitive, and to assess their respective impacts on power sources and the environment. Lessons learned from this study can be applied well beyond France, at a time when a European maritime strategy is taking shape.

ICOE 2008: Second International Conference on Ocean Energy – Brest, France
EDF and Ifremer organised the Second International Conference on Ocean Energy (ICOE 2008), in partnership with IEA-OES and the European Ocean Energy Association (EU-OEA), from 15 to 17 October 2008, in Brest. This conference, placed under the high patronage of Jean-Louis Borloo, Minister of State, Minister for Ecology, Energy, Sustainable Development and Town and Country Planning, covered all the ocean energy sources and involves all the players in the sector, in particular industrial ones. ICOE registered 480 participants from 25 countries.

The IPANEMA initiative
In 2008, realising the urgency to build a French road map for the development of marine renewable energies, ADEME, MEEDDAT, industrial companies with interests in marine energies and marine research organisations, will contribute, in a shared and open approach for mainland and overseas France, to the development of industrial and scientific activities on marine renewable energies.

Thus, ICOE 2008 offered an excellent frame for all partners to sign the French “IPANEMA” initiative (National Partnership Initiative for Marine Renewables to Emerge, www.ipanema2008.fr). Partners are MEEDDAT, Ifremer, ADEME, seven regions, and EDF and DCNS corporations. Since mid-October, around 50 entities from research to industry have joined as partners in the initiative. Its objectives are to promote a scientific sector, to develop test sites at sea and to contribute to developing an industrial sector by 2020. The working group IPANEMA has a mandate to propose strategies towards these objectives. Its conclusions should be made public in late spring 2009.

SEM-REV: The French Wave Energy Test Site
The first French wave energy converter test site is being built under a regional development French programme. The project named SEM-REV, as the French acronym for Experimental Test Site for Wave Energy Converters, will be located on the Atlantic coast in the Pays de la Loire region and will be operational by summer 2010. Planning and developing the grid-connected test site will be the first in France.

Stakeholder Consultation
A regulatory consent roadmap has been outlined for project development jointly with the public authorities. This roadmap is meant to become a baseline for future wave power projects.

A thorough consultation process has been started involving different actors related to the project. The involved stakeholders below have received project information and have been consulted on different technical and administrative aspects.

- Commercial fisheries: Consultation process has started in 2007 and is still undergoing. This work was finally structured by the Department of Maritime Affairs (*Direction des Affaires Maritimes*) and the local and regional Fisheries Committees.
- Maritime navigation authorities: Technical meetings are planned with the public bodies in charge of maritime security to discuss the maritime beaconing layout and signal regimes.
- Environmental public bodies: Several public organisations are taking part of the environmental impact assessment study. Mitigation solutions are being proposed to the different stakeholders.
- Local communities: Public meetings have been held since November 2007. Public acceptance of the project is well perceived. The project developer regularly publishes all items related to the wave test site under the coordination of the local adjacent towns.

Overseas Country Context: Reunion Island (France – Indian Ocean)
In 2005, the Reunion Island Regional council conducted a study on the potential of wave energy in Reunion Island, which then selected a site with high potential for recovery of wave energy south of the island. In 2009, an industrial consortium will conduct a feasibility study for the deployment of Pelamis technology. The aim is to launch the deployment in Reunion Island via the Saint Pierre site, which may subsequently receive other types of technology. In 2009, a campaign to measure sea currents will take place in St. Paul Bay to characterise ocean currents. It will evaluate the opportunity develop this sector.

In 2008, through co-financing of Regional Energy Agency (ARER), the city of Port and TCO (Territoire des Communes de l'Ouest), ARER conducted a study on the opportunity to develop Ocean Thermal Energy Conversion (OTEC) and use of deep cold water in the city of Port. Contacts have been made recently with a French industrial group to study the establishment of an OTEC demonstration in Reunion Island.

Through the PRERURE (Regional Plan of Renewable Energies and Rational Use of Energy) of the Reunion Island Regional Council and GERRI (Green Energy Revolution – Reunion Island) of the French state, the challenge of Reunion Island is electrical energy independence by the year 2025-2030. Marine energy will be an integral part of the 2025-2030 energy mix and ocean thermal energy is essential to achieving this objective of self-sufficiency.

Research and Development

ADEME
ADEME is the French Agency for the Energy and the Environment. It is a government institution expert in energy and environment that belongs to the Energy and Ecology Ministry as well as the Research Ministry. ADEME supports research and development actions in every ocean energy field. ADEME supported tidal systems, such as the SABELLA tidal turbine from HydroHelix or the Harvest project (transverse axis turbine) from the EDF / CNRS / Grenoble INP, and wave systems such as the SEAREV project from the Ecole Centrale de Nantes.

ADEME also promotes various research actions in the field: state of the art of marine energy in Europe from Ifremer, the prospective works from Ifremer about the possible development scenarios in ocean energy, or more fundamental works such as the methodological studies to assess the wave potential.

Ifremer
Accurate sea-state descriptions are more and more required to correctly assess the wave climate. A better knowledge of time and space wave variability may benefit further technological develop-

ments of marine renewables such as the deployment of wave energy converters in wave-farms along European coastlines. The aim of the on-going work at Ifremer is to provide methods to accurately estimate, through detailed climatologies, the effective wave energy potential with regard to the hydrodynamic behaviour of the energy converter.

Considering predictability of marine currents in time and space, marine current energy converters are promising systems for conversion of ocean energy. Nevertheless some perturbations are induced by the bathymetry, the turbulence and the ocean waves' effects. Two mathematical tools have been developed to model the propagation and interaction of waves and current in order to study the global kinematics on the whole fluid. Then some high frequency measurements on a typical deployment site with strong currents have been done to complete the study.

In 2008, Ifremer has started to develop mathematical tools under a Ph.D. programme to help with the environmental impact assessment of future commercial installations. A three-dimensional software model taking into account the non-stationary evolution of the wake emitted by a three-bladed horizontal axis turbine is being developed in order to assess disturbances generated on its close environment. This mathematical work will be validated in 2009 from experiments carried out in the Ifremer flume tank.

The durability of materials used for ocean energy conversion systems is a critical element in establishing reliable long-term performance. A study on the interaction between sea water and cyclic loading of fibre reinforced composites was launched in 2007 at Ifremer, and a PhD study is currently underway. This work is being performed in close collaboration with glass fibre and resin suppliers.

Since April, Ifremer, EDF and the SME Actimar contribute to the FP7 European project EquiMar, which aims at proposing protocols to pre-normalise wave and tidal energy sources by 2011.

Ecole Centrale de Nantes
Recent marine renewable energy research and development activities at the Fluid Mechanics Laboratory, a mixed research unit of the Ecole Centrale de Nantes and the National Scientific Research Centre (CNRS), include projects in the following fields:

- WEC farm and multi-body interaction modelling and experimentation
- Wave energy resource modelling and real-sea monitoring
- An offshore floating wind power project
- Marine current turbines hydrodynamic modelling

SATIE Laboratory (CNRS – ENS Cachan Britain)
SATIE is involved in the optimisation of the design of the chain of all-electric conversion of a direct conversion wave energy converter. The generation system includes a generator and magnet direct drive associated with a power electronics converter. It is optimised to minimise production costs per kilowatt-hour in the context of SEAREV (ECN).

Ecole Navale (Brest – Brittany)
The Mechanical Engineering Department of the Research Institute of the French Naval Academy is involved in basic and applied research related to marine renewable energy. It includes the development of theoretical, mathematical and experimental methods to study specific marine current turbines.

Two systems are being studied. The first one is based on rim-driven technology, including turbine and electrical engine models. The second one is a cross-flow turbine based on a Darrieus-like system, on which optimised dynamic pitch changes are examined in order to optimise the foil hydrodynamic angle during the main revolution to increase efficiency.

DCNS

The DCNS group – Europe's leading player on the world market naval defence systems with high-added-value – combines a 400-year-old history with a proven capacity for innovative and reliable solutions.

Since 2008, DCNS has considered expanding its activity to the energy market and especially renewable ocean energies. Its aim is to offer to utilities reliable turn-key systems and associated maintenance, based on its very large built-in know-how portofolio.

During 2008, DCNS has investigated all the major renewable ocean energies, with a special focus on OTEC (Ocean Thermal Energy Conversion) systems and floating wind turbines through an involvement in the WINFLO project (floating wind energy device).

EGISEAU

EGISEAU has developed a software model which allows the evaluation of the energy potential of marine areas and their economic interest. The ENERMER software works for all marine renewable energy resources (wind, wave, current and ocean thermal gradient). It integrates data from the physical environment and from environmental, technical, economic and other uses.

Technology Demonstration

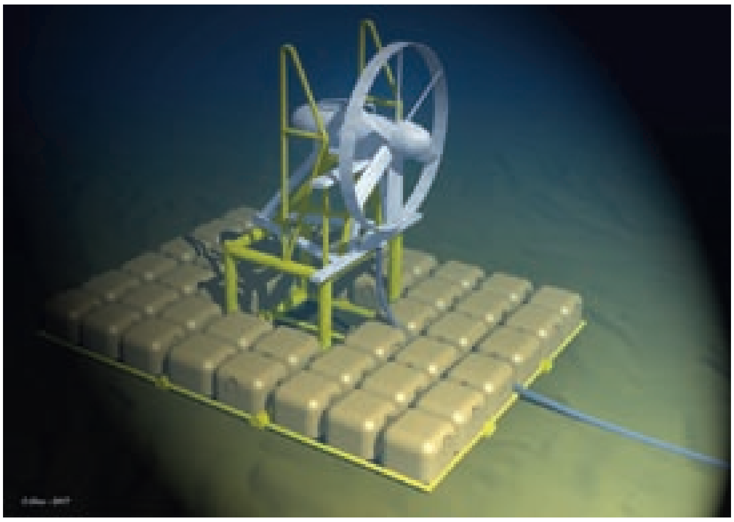
Sabella

In 2008, the British Sabella Consortium, formed with four local companies (Hydrohelix Energies, Sofresid Engineering (SAIPEM Group), In-Vivo Environnement, Dourmap), completed a significant trial campaign with a 1/3-scale pilot tidal turbine.

Mainly supported by the Brittany Regional Council and ADEME, which granted 40% of a EUR 750,000 total budget, the Sabella Consortium designed a pilot turbine with experiment and measurement objectives. The main specifications of this horizontal axis turbine are: a 3-m diameter rotor, six fixed and symmetrical blades, anchored structure with dead-weights, permanent magnet generator, thermal dissipation for electric production, optical fibre link to shore for data transmission.

The machine, named "Sabella D03," was installed in the Odet River estuary, offshore Bénodet from April to August 2008. With Ifremer assistance, the Sabella Consortium showed a very neutral environmental footprint, and checked the appropriate design for future diverless full-size turbines, the mechanical behaviour facing tidal current stresses, production yield in line with the mathematical model, and some antifouling processes. In December 2008, Sabella D03 was re-immersed on the same site for an additional winter trial campaign.

At the end of 2008, the Sabella Consortium partners founded Sabella SAS, a joint company dedicated to the finalising technical development and a full-size demonstration using a Sabella D10 turbine (10-m rotor) prior to an industrial and commercial launching planned in 2010. Sabella SAS is developing a funding phase for private investors.



Copyright Jacques Ruer (SAIPEM SA)

The Hydro-Gen project

Hydro-Gen is a surface marine current device to be moored in areas with strong currents (more than 5 knots), using a regular naval technology. Hydro-Gen technology is well suited to areas with shallow waters and relatively protected from heavy seas research and development test was conducted with the assistance of engineering schools including ENIB and IRENAV (Brest) and supported by ADEME and the Brittany Regional Council. A 1:10-scale prototype has been in sea trials since May 2006. Sea trials of the fourth prototype have just ended. The next phase will be building a machine scaled to one-third (10 x 5 m, 30 to 70 kW) or pre-industrial level 1 (30 x 20 m, 300 to 750 kW) to be connected to the network.

EDF: The Paimpol-Bréhat Demonstration Project

After more than four years of dialogue and comparative studies between the Brittany and Normandy coasts, the Paimpol-Bréhat (Brittany) tidal site was officially chosen and announced in July. In October, during ICOE 2008, the CEO of EDF announced that the Irish company OpenHydro Group Ltd had been selected to build a first series of 4 to 10 fully submerged machines on this Paimpol-Bréhat site to produce electricity from tidal currents. These 4 to 10 machines represent a total capacity of 2 to 4 MW, which should progressively be connected to the grid from 2011. Other technologies could be tested on this site.

Copyright Hydro-Gen

INDIA

Purnima Jalihal, NIOT

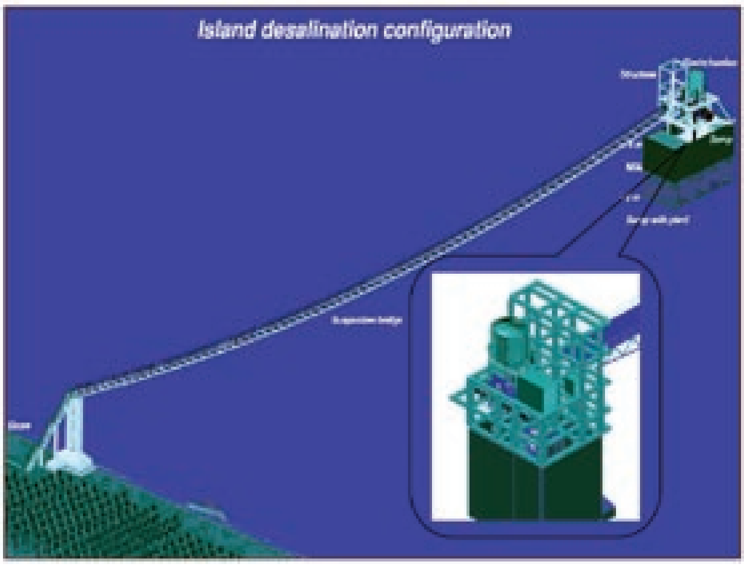
Policy and Prospects

Ministry of Earth Sciences under the government of India works through National Institute of Ocean Technology (NIOT) to carryout research and development works in ocean technology. The works involve developing technologies such as wave-powered devices and low-temperature desalination under this programme of ocean renewable energy. Besides NIOT, there are a few independent groups, such as the Indian Institute of Technology, Chennai, that work on laboratory-scale models of the wave-powered devices.

Research and Development

India has a vast coastline of about 7 500 km and a lot of islands. India is actively undertaking ocean renewable energy research with the following objectives:

1. Providing a viable alternative source for drinking water needs of the mainland and island population.
2. Developing technologies towards low-powered wave energy devices for the needs of remote islands.
3. Developing OTEC-based energy devices to make desalination plants both on barges and self-sufficient islands.



A view of the proposed 100 m3/day island-based desalination plants to be set-up at Andrott, Agatti and Minicoy Islands in the Lakshadweep Region.

The primary areas of research revolve around desalination based on ocean thermal gradient and wave-powered devices.

National Institute of Ocean Technology, Chennai

The institute is the technical arm of the Ministry of Earth Sciences, Government of India, working towards development and demonstration of field-scale models of ocean renewable energy devices. As a part of its mandate, NIOT has setup a 100 m^3/day island-based low-temperature thermal desalination plant at Kavaratti, India, in 2005 and demonstrated a 1 000 m^3/day experimental barge-mounted desalination plant off Chennai Coast, India, in 2007. Currently, work is underway to establish three island-based desalination plants in three remote islands in the Lakshadweep region of India, scheduled to be commissioned by June 2009. NIOT is also working on wave-powered devices meant for remote islands.

Indian Institute of Technology, Chennai

The institute has research groups working towards development of laboratory-scale wave energy devices, and development of technologies for distribution and restructuring of wave energy.

Technology Demonstration and Projects

	Low Temperature Thermal Desalination	
	Island Based Plants	
Technology	Ocean Thermal Gradient Based Desalination	
Size and Scale	100 m^3/day operational plant for island	100 m^3/day operational plant for island
Project Name	Kavaratti desalination plant	3 island desalination plants
Location of the Plant	Kavaratti, India	Agatti, Andrott, and Minicoy, India
Developer	NIOT	NIOT
Current Status	Plant is operational, supplying to the island	Components are under fabrication, Plants expected to be commissioned by June 2009
Results Achieved	Successfully handed over to island in 2006	Design is completed
Plans	Setup of similar plants in other islands of the region	Setup of similar plants in other islands of the region
Funding	Public	

NETHERLANDS

P. C. Scheijgrond, Ecofys Netherlands BV

Policy and Prospects

Energy from water saw renewed interest in 2008 from governmental bodies and other stakeholders. Although there is no formal policy yet for ocean energy technologies, the topic is on the agenda for bodies such as Senter-Novem, Ministry of Economic Affairs and Directorate-General for Public Works and Water Management (Rijkswaterstaat).

In August 2008, Deltares published a study outlining the potential for water as a source of renewable energy in the Netherlands. In September a stakeholder workshop was organised bringing together some 100 delegates, including representatives from government. A plan was made to include water energy technologies in the policy frameworks (Energy Transition Paths) for renewable energy development in the Netherlands.

Research and Development

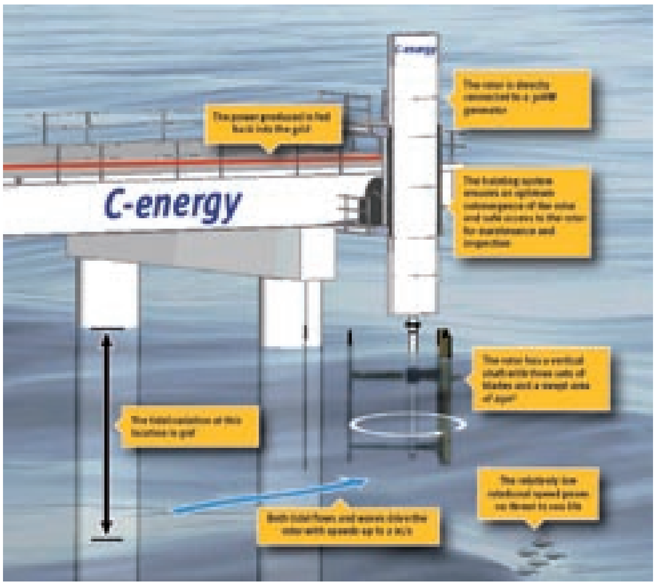
Key players and research and development plans include:

- **Alkyon Hydraulic Consultancy & Research** offers expertise in coastal and offshore hydraulic engineering and research. They are developers of the Dynamic Tidal Power system.
- **The Energy Centre Netherlands (ECN)** develops high-level knowledge and technology for sustainable energy systems and transfers it to the market. In the past, they have cooperated on ocean energy projects.
- **Ecofys Netherlands BV** is the largest independent consultancy dedicated to sustainable energy in the Netherlands. Several studies related to tidal, wave and osmotic energy have been published for local and national authorities. Ecofys is also developing the Wave Rotor.
- **Deltares,** a Dutch research institute for water, soil and subsurface issues, is partner in the management of the Water Innovation Program (WINN) of Rijkswaterstaat, Ministry of Transport and Public Works
- **KEMA** is a commercial enterprise, specialised in high-grade business and technical consultancy, inspections, measurements, testing and certification related to products, processes and equipment for the production, distribution and use of electricity. It has carried out a number of feasibility studies for pumped storage concepts.
- **Teamwork Technology BV** provides technology and business development of sustainable technology, modelling of the physical process, engineering of demonstration equipment and monitoring during testing. It operates a test site for (tidal) turbines. Specialist in electrical direct drive equipment and grid connections.
- **Technical University of Delft** is involved in the technical development of both generic and device-specific issues ranging from direct drive generators, hydraulic computation modelling and systems development.
- **Wetsus** is a centre for sustainable water technology, especially research into Reversed Electro Dialysis (RED): prevention of fouling, system and membrane design

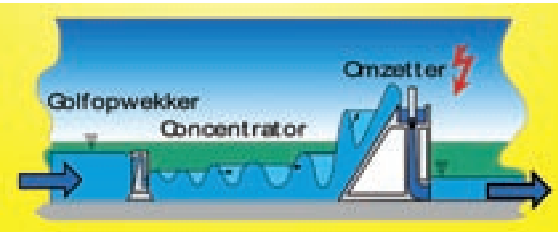
Technology Demonstration and Projects

Econcern Wave Rotor

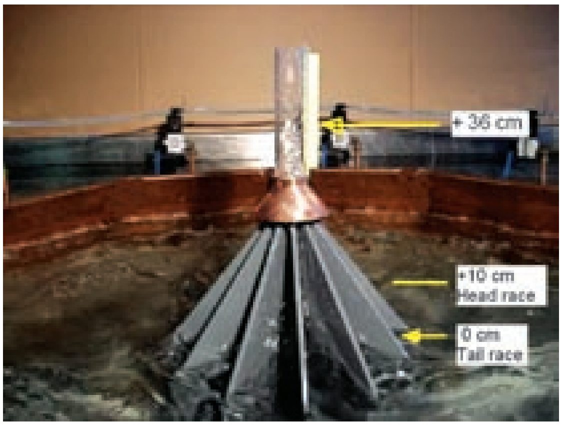
The Wave Rotor is an innovative wave and tidal turbine developed by Econcern and works on simple wind turbine principles under water. The turbine is capable of converting both tidal and wave energy directly into electrical power. The Wave Rotor exploits the orbital velocities within waves and utilises the principle of hydrodynamic lift to turn a set of blades around a vertical axis.



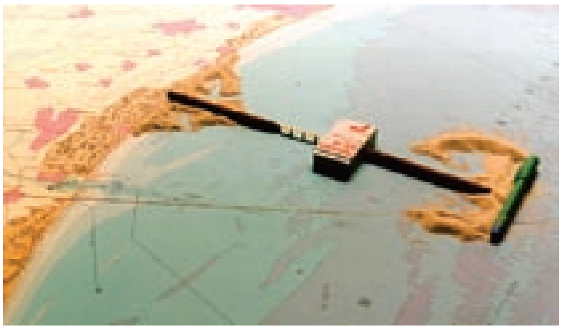
30-kWp protototype Wave Rotor to be deployed early 2009 in the Westerschelde.



Hydropower lens, by Entry Technology BV.



Hydropower lens, by Entry Technology BV.



Dynamic Tidal Power schematic concept for Dutch coast, by Alkyon and H2iD.

Experimental trials were successfully completed in 2004 at NaREC on a one-tenth-scale model of Ecofys' Wave Rotor and also at Ifremer in Brest in waves and tidal currents in 2007. The NaREC test was funded via the Carbon Trust's Marine Energy Challenge Programme. A grid-connected model test in the sea in Denmark was funded by the Danish Wave Energy Programme.

In 2008, a construction was designed and engineered for a 30-kWp rated Wave Rotor, which will be suspended from a pier in the Westerschelde early 2009 in cooperation with the city council of Borsele, Total NV and eight other partners in the C-Energy consortium (www.C-Energy.nl).

For more information, see www.C-Energy.nl .

Entry Technology BV Hydropower Magnifier
Entry Technology BV in Rhenen, Netherlands, is working on a concept called the Hydropower Magnifier. The physical principle behind this system is based on wave energy: Waves generated by a low head wave maker are concentrated to a higher energy state (head) and in a final step converted into electrical power. Following 2-D and 3-D computational modelling, a proof-of-concept physical test device built in 2008 resulted in a head concentration factor of 3.6. The economic, ecological and technical feasibility of the concept was also assessed. The studies continue to be supported under the NEO programme (New Energy Research) of SenterNovem.

H2iD Dynamic Tidal Power (DTP)
Alkyon Hydraulic Consultancy & Research and proposes to build a very long artificial T-shaped dam perpendicular to the Dutch coast and to the tidal flow. The existence of such dam in a tidal flow creates a hydraulic head over the two sides which can be used to drive conventional low-head hydro turbines mounted in the dam. In a tandem array (i.e., two dams) with proper spacing with respect to the tidal wave, the hydraulic head of both T-dams combined could yield a virtually constant power when producing into the same grid.

The validity of this tidal power concept was elaborated in a study in 1997 assigned by SenterNovem. A pilot project to test the required low-head turbines is planned to start 2009 in one of the dikes of the Delta Project (Grevelingen Dam). The feasibility of a pilot project for a large T-dam in China has recently been considered. This should take place in the framework of a joint Sino-Dutch DTP-Platform.

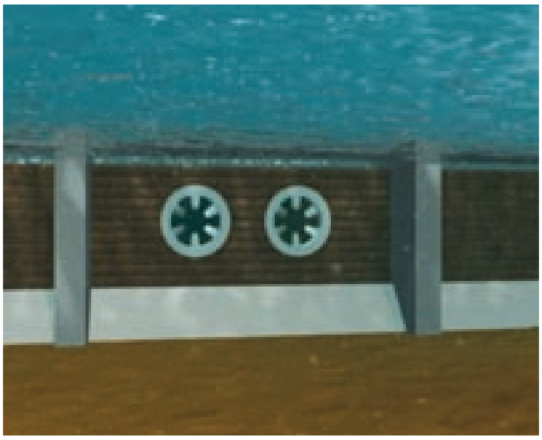
HydroRing Renewable Hydro Energy
The HydroRing is being developed by HydroRing BV. HydroRing is a water-driven generator that requires only a low head to generate a reasonable amount of energy.

The turbine is an axial flow rotor with active or passive rim bearings, and magnetic or mechanical bearings. The power take off is on the rim of the rotor housing preventing the need for a central axis. Since there is no need for a central shaft, it is expected that fish can pass easily through unused space in the middle. The generator is designed so that it will fit in existing locks and barrages in waterways without changing their ecological footprint.

The first assignment of the company was a pilot to ascertain the possibility of realising energy neutrality for existing locks, dams, barrages and dikes in rivers and channels in the Netherlands on behalf of Directorate-General for Public Works and Water Management of the Netherlands (Rijkswaterstaat).

During 2008, Project Rijkswaterstaat a proof of principle test was constructed with a Dutch syndicate of development partners. Design and construction of the prototypes is under way. Early in 2009, a pilot project will start on the Maas River at the Sambeek locks. A Dutch EOS DEMO (New Energy Research) grant was awarded for a field demonstration together with the Dutch Directorate for Public Works and Water Management (Rijkswaterstaat).

Further opportunities for pilot projects are explored in India, Thailand, Indonesia, Laos, Scotland, Malesia and Vietnam.



Artist impression of two units of a HydroRing in a sluice gate underwater (www.HydroRing.eu).

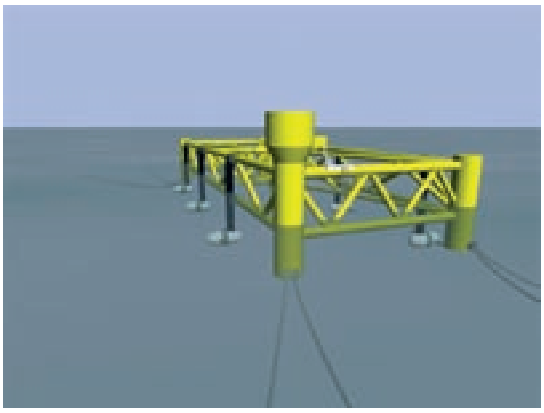
Tocardo BV Tidal Energy
Tocardo is a Dutch tidal device developer with a history of 12 years in offshore engineering and development of renewable energy generating devices.

Current Tocardo Aqua series comprise variable-speed horizontal-axis turbines with a two-bladed fixed-pitch rotor. To eliminate a maintenance intensive gearbox, the turbines are equipped with a permanent magnet direct drive (PMDD) generator developed in-house. A smart and simple blade reversing mechanism (patented) allows the turbine to operate efficiently in bi-directional flows. The Aqua turbine series are based on a 2.8 m prototype turbine, which was deployed in 2005 in the IJsselmeer barrage near Den Oever.

Two Tocardo Aqua turbine series currently exist:

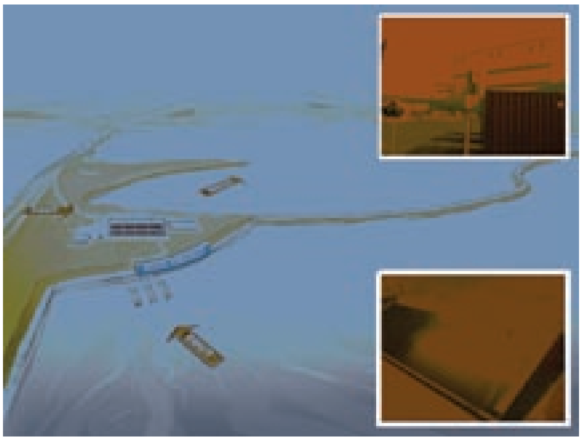
- Aqua Inshore turbine is applicable in locations where high-speed water flows occur near civil structures like bridges, sluices and dams, and where opportunities exist to connect the device to these structures. The size of the turbine is dependent of the size of the water channel. a pre-commercial 2.80-m diameter 45-kW Tocardo Aqua Inshore turbine was installed in summer 2008. The turbine will be operational for 10 years as a demonstration of tidal energy generation. Plans exist to expand the project with a number of additional turbines.
- Aqua Offshore turbine will be deployed in offshore high-speed waters like the Pentland Firth in Scotland. In October 2008, plans were unveiled to establish a 0.5-MW offshore pilot tidal farm in the Marsdiep sea strait. The farm will consist of six 10-m diameter Aqua Offshore turbines, suspended from a floating platform. In addition, a consortium of companies was set up to develop a 10-MW offshore tidal demonstration farm in the Pentland Firth. Recently, a firm 5-MW grid connection was acquired to feed the future tidal energy into the UK national grid.

Tocardo Aqua Inshore at Den Oever – parking position (www.tocardo.com).



Tocardo Aqua Offshore – artist impression of floating structure (www.tocardo.com).

Wetsus – REDstack Salinity Gradient Energy
REDstack is a spinoff company from Wetsus. The scientific research of Wetsus on the Reverse Electro Dialysis (‘Blue Energy’) conversion technique is applied at REDstack into a technical design of a stack assembly of membranes and electrodes to generate electricity from salt and fresh water. When fresh water



Artist impression of a salinity-gradient power plant at the IJsselmeer; inset top right: RED pilot in Harlingen; inset bottom right: pre-treatment of RED (www.redstack.nl).

flows into sea water, huge energy can be derived from the difference between the chemical potentials of concentrated and diluted salt concentrations. In several projects within the New Energy Research programme of SenterNovem, low-cost membranes and other key components are under development. The promising results raised interest from different industrial and power supply companies and water authorities to invest in pilot tests. Parties agreed on the following development path:

- Industrial pilot (kW-scale) on saline flows in a salt factory (Financial support by SenterNovem, Innowator project; 2008-2010)
- Feasibilty study and definition of requirements for a communal power plant of 200 MW at the Afsluitdijk (Private funding, 2008)
- Communal pilot (10-40 kW) on sea water and river water (2009-2010) at the Afsluitdijk
- Communal pilot (1 MW) on sea water and river water (2010-2012) at the Afsluitdijk

RUSSIA

Alexander A. Temeev, Director of Applied Technologies Company Ltd (ATC)

Policy and Prospects

Various studies, evaluations and other research evidence on renewables available in Russia demonstrate that there is enormous potential as well are huge technical-economic opportunities for cost-effective energy efficiency investments in the industrial, residential and heating sectors. Renewable energy sources in Russia can play a significant and cost-effective role in energy supply in many geographic regions. However, despite the evidence shows that Russian technological capabilities to exploit these technical-economic potentials are strong, the market-related capabilities are still weak. Actual power production and consumption in Russia is dominated by fuel-burning technologies (Energy Information Administration / International Energy Outlook 2007). Approximately 54% of primary energy production consists of natural gas burning, 19% oil product burning, 16% coal and other solid fuels burning, 5% of production is from nuclear power and about 6% is from hydro power and other renewables.

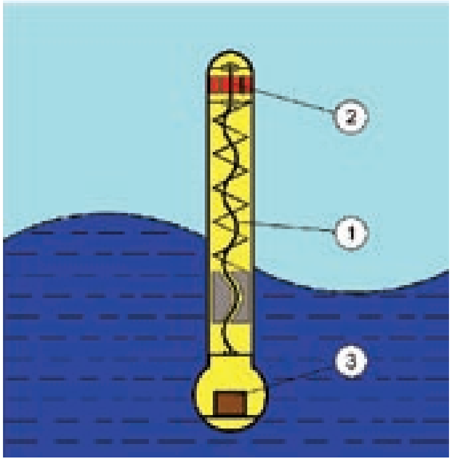
The actual annual energy production is at a level of 26 to 31 quadrillion Btu. The structure of the electricity production in Russia is characterised by the similar indexes. Approximately 72% of the electricity production is from burning coal, oil products and gas; about 13% is from nuclear power and about 15% is from hydro power and other renewables. At the same time, when hydroelectricity and combustible renewable (like wood and waste) are excluded, the share of all other renewable resources makes up less then 0.1% of the overall energy production. Russia receives practically no share of its energy supply from renewable energy sources.

Public funding/governmental support is provided through State Contract No. 02.516.11.6108 on the development of a dynamic model of Float Wave Electric Power Station (FWEPS) module (amount of financing: USD 30 000).

Research and Development

Key institutions with research and development activities in wave and tidal energy include the following:

- **The Applied Technologies Company Ltd (ATC)** develops an offshore Float Wave Electric Power Station (FWEPS) as efficient means for sea wave energy conversion and technology for hydrogen production by means of sea water electrolysis (established in Moscow, Russia). (www.atecom.ru)
- **The Private Productive Science and Technical Company** is developing a wave energy converter for renewable energy systems, either floating or ground-based (established in Moscow, Russia). (ocean-power.narod.ru/index.html)
- **The Scientific Research Institute of Energy Structures Joint Stock Company** is developing an installation for tidal power conversion (established in Moscow, Russia). (www.niies.ru)



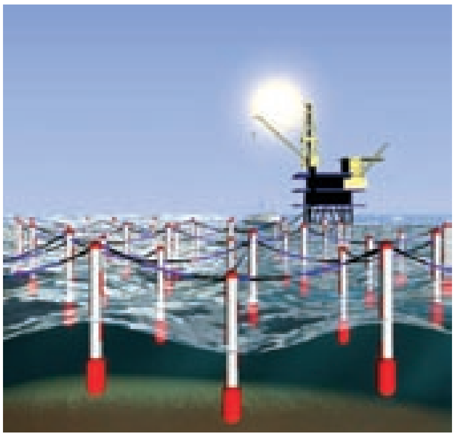


Diagram of single-module FWEPS and example of multimodule FWEPS use for the power supply of remote marine objects.

Technology Demonstration and Projects

Wave Energy

The demonstrational model of the Float Wave Electric Power Station (FWEPS) module and assembly units are at the completion stage of manufacturing, adjustment and test preparation. Next plans include the development of full-scaled 10-kW FWEPS and the development of multimodule grid installation.

The module of FWEPS consists of a mechanical wave energy converter, an electric generator and energy storage. They are maintained inside a sealed float capsule of an axially symmetric streamline shape. The float is placed on the sea surface in the direction of local vertical. The mechanical wave energy converter consists of an oscillatory system and a drive for an electric generator. Under the action of sea waves, the FWEPS float and inner oscillatory system are in continuous oscillatory motion. The drive, engaged with the latter provides a continuous electric generator rotation. Depending on mission, it is possible to develop both a single modular FWEPS for output power for units up to 50 kW and multi-modular installation in a grid form with a total capacity up to dozens of megawatts.

In 2008, the physical-mathematical and experimental simulation of FWEPS models was further explored. An experimental model in a sea basin with irregular waves and hull of FWEPS pilot module is under construction (yellow-black cylinder in the centre of picture).

Experimental model in a sea basin with irregular waves and hull of FWEPS pilot module under construction (yellow-black cylinder in the centre of picture).

Tidal Energy

Design studies for tidal power development have been conducted in Russia since the 1930s. As part of this work, a small pilot plant with a capacity of 400 kW was constructed in Kislaya Bay on the Barents Sea and commissioned in 1968. The location has now become an experimental site for testing new tidal power technologies.

Early in 2007, GidroOGK, a subsidiary of the Russian electric utility, Unified Energy Systems (UES), began the installation of a 1.5-MW orthogonal turbine alongside the original Kislaya Bay tidal facility. The experimental turbines will be thoroughly tested as part of a pilot project to assist in the design of large-scale tidal power plants.

There are currently two ambitious projects for TPPs in the Federation:

- Mezenski Bay (on the White Sea, in northern Russia): proposed capacity 15 GW, annual output 40 TWh
- Tugurski Bay (on the Sea of Okhotsk in the Russian Far East): 7.98 GW capacity, 20 TWh annual output

If the 1.5-MW experimental installation at the Barents Sea location proves successful, UES intends to embark on a programme for constructing giant-size TPPs such as those projected.

SOUTH AFRICA

Thembakazi Mali, South African National Energy Research Institute (SANERI)

Ocean Energy Policy

A private member's bill has been brought before Parliament on a renewable energy feed-in tariff. Nersa, the regulator, has drafted a consultative paper which is out for public comment and the feed-in tariff guidelines will be out by the beginning of March.

Research and Development

Stelllenbosch has filed a patent on improvements on the Stellenbosch Wave Converter (SWEC). It has also submitted proposals as part of a consortium for FP7 and others with the Research Council of the UK. There are a number of projects on wave converters.

Technology Demonstration

There are no demonstration projects yet.

2008 Executive Committee

CHAIRMAN
Dr. Gouri S. Bhuyan
Powertech Labs Inc.
12388-88th Ave
Surrey, BC, V3W 7R7
Canada
E-mail: gouri.bhuyan@powertechlabs.com

VICE-CHAIR
Dr. John Huckerby
AWATEA
Panama Street
PO Box 25456
New Zealand
E-mail: mail@awatea.org.nz

VICE-CHAIR
Mr. Jochen Bard
Institut fuer Solare Energieversorgungstechnik, ISET
Kassel
Germany
E-mail: jbard@iset.uni-kassel.de

SECRETARY
Dr. Ana Brito e Melo
Wave Energy Centre
Av. Manuel da Maia, 36 – r/c dirto
1000-201 Lisboa
Portugal
Tel: +351 21 848 2655
Fax: +351 21 848 1630
E-mail: ana@wave-energy-centre.org

Past Chairs
Dr. Teresa Pontes (Portugal), 2002-2004
Mrs. Katrina Polaski (Ireland), 2005-2006

BELGIUM
Delegate Member
Mr. Gabriel Michaux
Federal Public Service Economy
Brussels
E-mail: gabriel.michaux@mineco.fgov.be

Alternate Member
Prof. Julien De Rouck
Ghent University
Zwijnaarde
E-mail: julien.derouck@ugent.be

CANADA
Delegate Member
Dr. Gouri S. Bhuyan
Powertech Labs Inc.
British Columbia
E-mail: gouri.bhuyan@powertechlabs.com

Alternate Member
Ms. Melanie Nadeau
CANMET Energy Technology Centre
Natural Resources Canada
Ottawa
E-mail: menadeau@nrcan.gc.ca

DENMARK
Delegate Member
Mr. Jan Bünger
Danish Energy Authority
Copenhagen
E-mail: jbu@ens.dk
Replaced by
Mrs. Hanne Thomassen
Danish Energy Authority
Copenhagen
E-mail: hth@ENS.DK

Alternate Member
Dr. Kim Nielsen
RAMBØLL
Virum
E-mail: Kin@ramboll.dk

EUROPEAN COMMISSION
Delegate Member
Mrs. Anna Gigantino
European Commission
Brussels
E-mail: anna.gigantino@ec.europa.eu
Replaced by
Mr. Thierry Langlois d'Estaintot
European Commission
E-mail: thierry.d'estaintot@ec.europa.eu

GERMANY
Delegate Member
Mr. Ralf Christmann
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Berlin
E-mail: Ralf.Christmann@bmu.bund.de

Alternate Member
Mr. Jochen Bard
Institut fuer Solare
Energieversorgungstechnik, ISET
Kassel
E-mail: jbard@iset.uni-kassel.de

IRELAND

Delegate Member
Mr. Graham Brennan
Sustainable Energy Ireland
Dublin
E-mail: Graham.Brennan@sei.ie
Replaced by
Mr. Eoin Sweeney
Sustainable Energy Ireland
Dublin
E-mail: Eoin.Sweeney@sei.ie

Alternate Member
Dr. Tony Lewis
Hydraulics and Maritime Research
Centre
University College Cork
Cork
E-mail: t.lewis@ucc.ie

ITALY

Delegate Member
Mr. Gerardo Montanino
Gestore Servizi Elettrici (GSE)
Roma
E-mail: gerardo.montanino@gsel.it

Alternate Member
Prof. António Fiorentino
Ponte di Archimede International
Messina
E-mail:
antonio.fiorentino@fastwebnet.it

JAPAN

Delegate Member
Dr. Yasuyuki Ikegami
Institute of Ocean Energy, Saga
University
Saga-city
E-mail: ikegami@ioes.saga-u.ac.jp

Alternate Member
Dr. Shuichi Nagata
Institute of Ocean Energy, Saga
University
Saga-city
E-mail: nagata@ioes.saga-u.ac.jp

MEXICO

Delegate Member
Dr. Sergio Alcocer
Instituto de Ingeniería UNAM
Mexico DF
E-mail: salcocerm@ii.unam.mx

Alternate Member
Dr. Gerardo Hiriart
Instituto de Ingeniería UNAM
Mexico DF
E-mail: ghiriartl@ii.unam.mx

NEW ZEALAND

Delegate Member
Dr. John Huckerby
AWATEA
Wellington
E-mail: mail@awatea.org.nz

Alternate Member
Mr. Tara Ross-Watt
AWATEA
Wellington
E-mail: bluesunenergy@yahoo.co.nz

NORWAY

Delegate Member
Mr. Petter Hersleth
Statkraft SF
Oslo
E-mail: petter.hersleth@statkraft.no

Alternate Member
Mr. Tore Gulli
Fred Olsen Ltd
Oslo
E-mail: tore.gulli@fredolsen.no

PORTUGAL

Delegate Member
Dr. Teresa Pontes
INETI/LNEG
Lisbon
E-mail: teresa.pontes@ineti.pt

Alternate Member
Prof. António Falcão
Department of Mechanical
Engineering
Instituto Superior Técnico
Lisbon
E-mail: Falcao@hidro1.ist.utl.pt

SPAIN

Delegate Member
Mr. Angel Chamero Ferrer
Ministerio de Industria, Turismo y
Comercio
Secretaria General de Energia
Madrid
E-mail: achamero@mityc.es

Alternate Member
Mr. Jose Luis Villate
ROBOTIKER - TECNALIA
Energy Unit
Bizkaia
E-mail: joseluis@robotiker.es

SWEDEN

Delegate Member
Dr. Susanna Widstrand
Swedish Energy Agency
Eskilstuna
E-mail:
susanna.widstrand@
energimyndigheten.se

Alternate Member
Ms. Maria Danestig
Swedish Energy Agency
Eskilstuna
E-mail:
maria.danestig@energimyndigheten.se

UNITED KINGDOM

Delegate Member
Mr. Trevor Raggatt
Marine Energy Technologies
Renewable Energy and Innovation
Unit
Department of Energy and Climate
Change (DECC)
London
E-mail:
Trevor.Raggatt@decc.gsi.gov.uk

Alternate Member
Mr. Alan Morgan
Marine Energy Technologies
Renewable Energy and Innovation
Unit
Department of Energy and Climate
Change (DECC)
London
E-mail: Alan.Morgan@decc.gsi.gov.uk

UNITED STATES OF AMERICA

Delegate Member
Mr. Alejandro Moreno
US Department of Energy
Energy Efficiency and Renewable
Energy
Washington
E-mail: Alejandro.Moreno@ee.doe.gov

Alternate Member
Mr. Walt Musial
National Renewable Energy
Laboratory
Golden, Colorado
E-mail: walter_musial@nrel.gov

New Chairman's Biography

Dr. John Huckerby
Executive Officer, Aotearoa Wave and Tidal Energy Association
IEA-OES Chairman 2009-2010

John Huckerby is the director of Power Projects Limited, an energy industry consultancy advising overseas energy companies, domestic utilities, public sector and government organisations on investments in New Zealand's energy industry. Since 2001, Power Projects has had a strategic interest in marine energy. It is currently involved in the WET-NZ research and development programme, which has developed a point-absorber wave energy converter.

John is also the founder and Executive Officer of the Aotearoa Wave and Tidal Energy Association (AWATEA), a marine energy industry association formed in April 2006. As well as being New Zealand's representative to the IEA's Ocean Energy Systems Executive, he is also New Zealand's representative to the International Electrotechnical Commission's TC114, a technical committee set up to establish technical, environmental and performance standards for marine energy.

John has a Ph.D. from Imperial College in London and an MBA from Henley Management College. He is a Chartered Engineer and a member of the Energy Institute, the Royal Society of New Zealand and the Institute of Directors in New Zealand.

IEA-OES Secretariat
Wave Energy Centre
Av. Manuel da Maia, 36, r/c Dto.,
1000-201 Lisbon, Portugal

IEA-OES Website:
WWW.IEA-OCEANS.ORG