International Journal of Marine Energy 11 (2015) 84–104

Contents lists available at ScienceDirect

International Journal of Marine Energy

journal homepage: www.elsevier.com/locate/ijome

# Ocean energy development in Europe: Current status and future perspectives

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ARTICLE INFO

*Article history:*
Received 16 March 2015
Revised 21 May 2015
Accepted 29 May 2015
Available online 6 June 2015

*Keywords:*
Blue energy
Ocean energy
Wave energy
Tidal energy
Strategic energy technology

ABSTRACT

Ocean energy has the potential to play a significant role in the future energy system, whilst contributing to the reduction of carbon emissions and stimulating economic growth in coastal and remote areas. Ocean energy has attracted increasing interest, particularly in the EU, which is currently at the forefront of ocean energy development.

Tidal and Wave energy represents the two most advance types of ocean energy technologies. In the EU, the aim is to reach 100 GW of combined wave and tidal capacity installed by 2050. In order to achieve these targets the sector needs to overcome a series of challenges and barriers with regards to technology readiness, financing and market establishment, administrative and environmental issues and the availability of grid connections especially in remote areas. Currently these barriers are hindering the sector's progress; its ability to attract inwards investments and to engage with the supply chain to unlock cost-reduction mechanisms. A number of policy initiatives and mechanisms have been put in place to ensure that ocean energy technologies could become cost-competitive in the short term, in order to exploit the benefits that these technologies could provide to the EU.



## 1. Introduction

The potential associated with ocean energy technology, in terms of security of supply, economic growth and reduction of $CO_2$ emissions has fostered an increasing interest in supporting the development of ocean energy technology and the establishment of ocean energy markets globally [1].

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http://dx.doi.org/10.1016/j.ijome.2015.05.001
2214-1669/

**Nomenclature**

| | |
|---|---|
| ADEME | Agence de l'Environnement et de la Maitrise de l'Energie |
| ARENA | Australian Renewable Energy Agency |
| CAPEX | Capital Expenditure |
| CRI | Commercial Readiness Index |
| DOE | US Department of Energy |
| EC | European Commission |
| EII | European Industrial Initiative |
| ENR | Syndicat des Energies Renouvelables |
| ETI | Energy Technologies Institute |
| EU | European Union |
| EVE | Ente Vasco de la Energia |
| FAI | Fundo de Apoio à Inovação |
| HAT | Horizontal-axis turbines |
| IEC | International Electrotechnical Commission |
| JRC | Joint Research Centre |
| KPIs | key performance indicators |
| LCOE | levelised cost of energy |
| MEAD | Marine Energy Array Demonstrator |
| MRCF | Marine Renewables Commercialisation Fund |
| MRPF | Marine Renewables Proving Fund |
| MS | Member States |
| NER300 | New Entrant Reserve |
| NREAPs | National Renewable Energy Action Plans |
| OEM | Original Equipment Manufacturers |
| OPEX | Operational Expenditure |
| OTEC | ocean thermal energy conversion |
| PTO | Power Take-Off |
| PV | Photovoltaic |
| R&D | Research and Development |
| RD&D | Research, Development and Demonstration |
| REIF | Renewable Energy Investment Fund |
| ROCs | Renewable Obligation Certificates |
| SEAI | Sustainable Energy Authority Ireland, See |
| SET-Plan | Strategic Energy Technologies Plan |
| TEC | Tidal Energy Converter |
| TIP | European Technology and Innovation Platform for Ocean Energy |
| TRLs | Technology Readiness Levels |
| WEC | wave energy converter |

The ocean energy sector comprises a number of different technologies, namely tidal energy, wave energy, ocean thermal energy conversion (OTEC) and salinity gradient, designed to harness power contained in our seas and oceans and convert it to renewable low-carbon electricity. To date, tidal and wave energy technology represents the most advanced ocean energy technologies, and those expected to become commercially viable in the short-medium term [2].

Despite the increased interested as demonstrated by political initiatives, such as the European Commission Communication "Blue Energy Action needed to deliver on the potential of ocean energy in European seas and oceans by 2020 and beyond" [3]; ocean energy deployments are proceeding at lower pace than expected and the ocean energy market is still to be established. In Europe, targets set by Member States (MS) in the 2009 National Renewable Energy Action Plans (NREAPs) expect wave and tidal energy capacity to reach 2250 MW or about 0.5% of the total installed electricity capacity in the EU by 2020. The sector aims to install 100 GW of wave and tidal energy capacity by 2050

[1]. However, current forecasts estimate a global installed capacity of only about 170 MW by 2020, which represents only 7% of the NREAPs targets [4]. The slow growth of the sector and delays in the formation of the market have forced key developers and OEM to either downsize, withdraw, or abandon their interest in developing ocean energy technology [5–7].

On the other hand, in 2014 the sector has also witnessed encouraging signs with the announcement of the construction of the first tidal array project, which is expected in 2016 in the United Kingdom [8] and ongoing construction of two wave energy projects in Australia [9] and Sweden [10]. The announcement of the awards for the second NER 300 call has seen the number of ocean energy arrays expected to be deployed in European waters by 2018 or earlier rising to four, in addition, a 10 MW OTEC plant will be built in Martinique [11]. Furthermore, the first tidal lagoon project is currently underway [12], and a 50 kW salinity gradient pilot-plant began operation in the Netherlands.

The ocean energy market is still in its infancy, and the sector has to overcome a number or challenges to prove the reliability and affordability of its technologies. This paper presents current state of play of ocean energy in 2014, focussing mainly on European developments. Emphasis is given primarily to wave and tidal energy technologies, which currently represent the most advanced forms of ocean energy. Furthermore, in terms of electricity production, wave and tidal energy are expected to make the most significant contribution in the near future, thanks to the availability and wealth of resources, particularly along the Atlantic coast.

This paper presents a critical review current status of ocean energy technologies, focussing on wave and tidal energy development in the EU. In Section 2, the EU policy context is presented, followed by an overview of the current barriers hindering the uptake of ocean energy technologies and of actions undertaken to overcome existing gaps (Section 3). The paper then focus directly on the development of tidal and wave energy technology in terms of market, innovation, project pipelines, costs and technology trends witnessed in 2014 (Sections 4 and 5). In Section 6, conclusions are presented.

## 2. European policy context

The EU is currently at the forefront of ocean energy technology development, and currently hosts more than 50% of tidal energy and about 45% of wave energy developers. To date, the majority of ocean energy infrastructure such as ocean energy test centres and deployment sites are also located in European waters as shown in Fig. 1 [13].

In order to support the growth and development of the ocean energy sector, in January 2014 the European Commission launched the Blue Energy Communication [3], which has highlighted the expected contribution of ocean energy in Europe, as well as setting a framework for the development and uptake of the ocean energy technologies by 2020 and beyond. The communication laid out a two-phase implementation plan which was initiated with the creation of the Ocean Energy Forum, a platform to bring together ocean energy actors and stakeholders to discuss common issues and identify viable solutions for the sector. The main output expected from the Ocean Energy Forum is to feed the development of a strategic roadmap defining targets for the industrial development of the sector

**Fig. 1.** Wave (left) and tidal (right) energy maps, identifying technology developers (in purple) and dedicated infrastructures in red [13].

and a clear timeframe for its implementation. The second phase (2017–2020) of the action plan foresees possibly the creation of a European Industrial Initiative (EII) for Ocean Energy, as already put in place by other renewable sectors (e.g. wind), within the SET-Plan framework [14].

## 3. Main barriers to ocean energy

Ocean energy technologies face four main bottlenecks: technology development, finance and markets, environmental and administrative issues, and grid availability [2,14]. In the context of the Blue Energy Communication, the Ocean Energy Forum has been asked to focus on first three topics; however grid issues are a rising concern among ocean energy stakeholders and developers who are looking to develop larger projects (>20 MW).

Currently, technological barriers represent the most important issue that the ocean energy sector needs to address in the short–medium term. Technology issues account for about 35% of the key priorities for the wave and tidal energy industries [14], and should be addressed with high priority in the next 12–18 months [15]. Overcoming technology issues is fundamental to identifying solutions to the other barriers slowing the sector's development, in particular financial hurdles.

### *3.1. Technology development*

Despite recent progress, no ocean energy technology developed has so far achieved the level of technological readiness required to be competitive with other RES or sufficient to ensure commercialisation of the technology [16,17].

One of the key issues that ocean energy developers need to address concerns the reliability and the performances of ocean energy devices; which are designed to operate in demanding environments and the lack of long-term reliability of currently hinders the roll-out of the technologies. Thus far, only few tidal energy devices have proven extensive operational records by employing components largely based on technology employed in the wind energy industry thus benefitting from know-how and knowledge transfer [18]. Critical components and sub-components, such as power take off (PTO), power electronics gearbox and moorings [19], play a significant role in ensuring overall device reliability. Wave energy designs, however, have not benefitted from such experience and most of the technology developed is still largely unproven and require further R&D, innovation and prototype testing and demonstration to achieve the required levels of reliability.

Another aspect that needs to be taken into account relates to the survivability of the devices, especially during storms or extreme conditions. A number of wave energy devices are being designed to operate in high-resource environments (>50 kW/m), where they will be exposed to strong wave regimes; however most of the deployment thus far have taken place in benign or mild-resource environments [20]. It is therefore necessary that innovative designs and materials are employed to ensure the long-term survivability of devices.

The lack of design consensus among ocean energy devices constitutes a further technological hurdle that the sector should overcome, relating both to overall converters design and to their components [14]. Tidal technologies are showing increasing design and component convergence, in particular with regards to the most advanced prototypes; a commonality which is still not witnessed within the wave energy sector. Achieving design consensus is essential to secure the engagement of the supply chain and unlock cost-reduction mechanisms through economy of scales.

Tidal energy technologies are expected to become commercially viable before wave energy; having shown higher design consensus among them, a more engaged supply chain, and having demonstrated reliability and survivability through extensive testing and operational hours [14,20]. Detail information on technology specific barriers are discussed further within the paper. Existing barriers are daunting the development of ocean energy, whose technologies are currently too expensive and unreliable to compete with other renewable and conventional technologies. Fig. 2 presents and overview of the levelised cost of energy (LCOE) for different energy generating technologies.

The high costs associated with ocean energy technologies combined with the unproven status of the technologies have hindered investors' confidence in the sector. There is a clear need for the sector

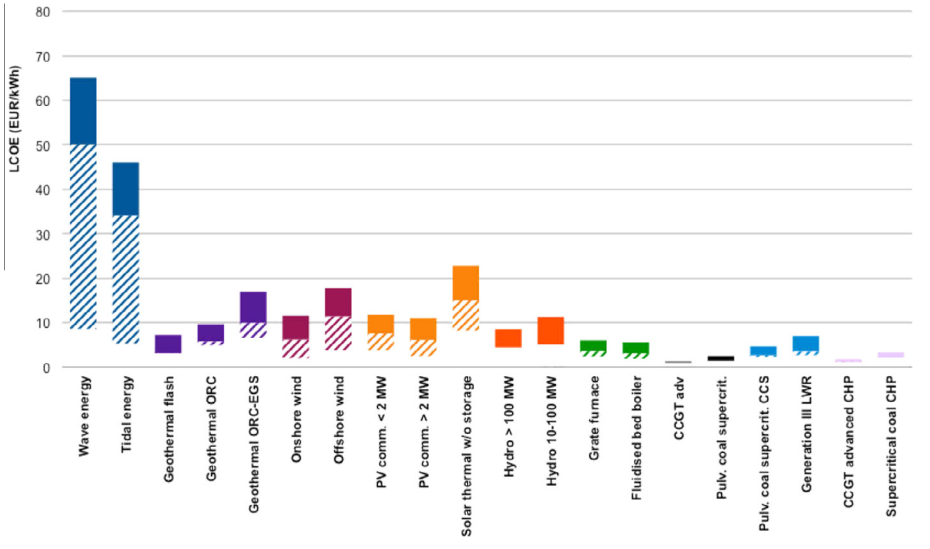


**Fig. 2.** LCOE for alternative and conventional energy technologies. Calculation based on [20]. Solid bars indicate current cost ranges, while shaded bars indicate expected future cost reductions.

to identify ways to facilitate technology development and deployment, to reduce the associated risk for investors; thus ensuring that wave and tidal technologies could reduce their costs and achieve competiveness with other renewable energy sources.

Developing and implementing technology-specific funds and key performance indicators (KPIs) ensures that technology development can happen without placing excessive expectations or unrealistic targets on a particular technology, thus reducing risk for both developers and investors. In this context, the Integrated Energy Roadmap initiative launched by the European Commission (EC) [21] has already identified KPIs defined for the whole sector. The development of standards, such as the one being developed by the International Electrotechnical Commission (IEC), which clearly define required levels of survivability and reliability for each TRL, would provide a clearer indication of the development of the technologies, as they improve towards commercialisation.

Nevertheless, in order to facilitate the progression of ocean energy technology to higher TRLs, it is also necessary to ensure that increased innovation and research efforts can take place, that best practice sharing is encouraged to spread the risk among stakeholders and that the development of test centres is supported. Activities and actions are currently being undertaken at global, regional and national levels. Key activities are summarised in Table 1.

### 3.2. Finance and markets

More than 50% of global RD&D investments in wave and tidal energy projects are in the EU [13]. Europe invested EUR 125 million in 2011 for R&D in ocean energy [20] (Fig. 3). Half of this investment came from industry and about a fifth from EU funds. 70% of EU R&D funding was dedicated to technology R&D [20]. The total R&D investment in ocean energy is about 10% of that for offshore wind. In addition, 5 demonstration projects have been awarded EUR 142 million from the NER 300 programme [13]. In 2011, wave energy attracted 58% of corporate investments, reflecting the role that this technology could play along the European coast; tidal energy attracted the remaining 42% [20].

Support mechanisms for emerging technologies need to be implemented with adequate timing in view of the market maturity of the technology [17]. While more technology-oriented mechanisms are needed during the first stages of technology development, market-push and market-pull instruments have to come to play at a later stage. Taking into account the current technological status of ocean

**Table 1**
Concerted activities and actions to overcome ocean energy technological challenges.

| Entity | Action | Type | Description |
|---|---|---|---|
| Ocean Energy Forum Ocean Energy Europe | TP ocean | European | The Technology and Innovation Platform for Ocean Energy is coordinating the technology stream of the Ocean Energy Forum. The stream has been divided in four main technological working groups, addressing: measurement and data, logistics and operations, prime movers, and components/subcomponents. Each working group is working to prioritise a series of topics that require R&D actions |
| Ocean Energy System | Annex II | Global | This annex aims to develop recommended practices for testing and evaluation of ocean energy systems, to enhance the comparability of experimental results. The work is separated into three main tasks, addressing site data, device development and guidelines for open-sea testing of devices. |
| | Annex V | Global | Annex V looks at facilitating the exchange and assessment of project information and experience from test centres. This work plays an important part in information sharing, to accelerate the technical understanding of ocean energy conversion technologies |
| IRENA | Policy | Global | IRENA comprises 135 states, and has recently produced a series of policy and innovation recommendations for ocean energy development |
| OceaneraNET | RD&D | European | OceaneraNET is an FP7 project comprising the research councils of different EU Member States. The project launched its first call for applications specific to technology development of ocean energy converters in October 2014 |
| MaRINET | RD&D | European | MaRINET is an FP7 project comprising 42 partners, providing access to experimental facilities across Europe at different scales for testing, research and optimisation of wind, wave and tidal energy technologies |

*Sources*: [22–24].

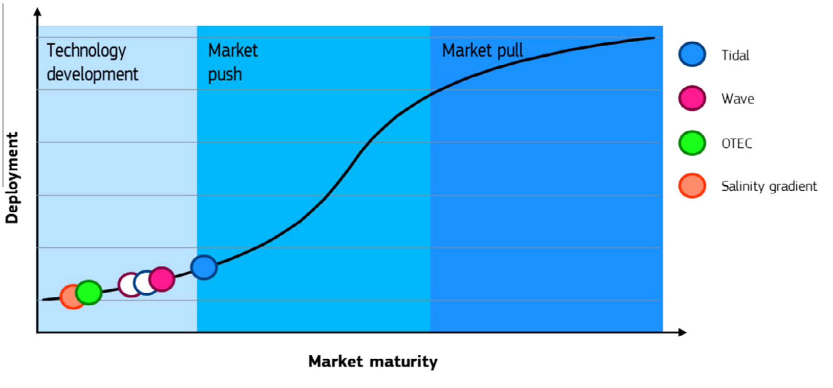


**Fig. 3.** Support mechanisms according to market maturity and deployment level.. Full circles represent technology front-runners, hollow circles represent the general market maturity for each technology. *Source:* [17].

energy, only leading tidal energy technologies have shown to be at a stage where market push mechanisms could help the uptake of the technology (Fig. 3).

The sector is at a critical stage, while market leaders are reaching financial close for the deployment of pre-commercial arrays; securing investment for demonstration and pilot arrays remains one of the main challenges the ocean energy sector currently faces, mainly due to high CAPEX for the first arrays [1,26]. Public funding and financial support for ocean energy technologies is still needed. An overview of the public support mechanisms implemented in EU Member States is presented in Table 2.

The level of public support available, through both market push and market pull mechanisms appears to be adequate to the current state of technology development and maturity of ocean energy technologies. Existing mechanisms are ready to accommodate the creation of the tidal energy market,

**Table 2**
Current market push and pull mechanisms for ocean energy from EU Member States.

| Country | Type | Description |
|---|---|---|
| United Kingdom | Pull | Renewable Obligation (ROCs) Scheme. Renewable Obligation Certificates (ROCs) buyout price set to 30 GBP in 2002/3 rising to 43 GBP in 2014/15. RO scheme will be replaced by a Contract for Difference (CfD) scheme in 2017 |
| | Push | Renewable Energy Investment Fund (REIF) Scotland, 103 m GBP |
| | | Marine Energy Array Demonstrator (MEAD), 20 m GBP. MEAD aimed at supporting two pre-commercial projects to demonstrate the operation of wave and/or tidal devices in array formation for an extended period of time |
| | | Energy Technologies Institute (ETI), about 12 m GBP for wave and tidal projects |
| | | The Crown Estate, 3 m GBP spent for enabling activities in the area of project development processes, committed to invest and manage an additional 5.7 m GBP in enabling actions for Pentland and Orkneys. Plans to invest up to 20 m GBP in first array projects |
| | | Marine Renewables Commercialisation Fund (MRCF) Scotland, 18 m GBP. 5 m GBP for enabling technologies |
| | | Marine Renewables Proving Fund (MRPF), 22.5 m GBP. Managed by Carbon Trust. Funds awarded to six projects |
| | | Saltire Prize, Scotland, 10 m GBP. For first device delivering > 100 GWh for two years |
| France | Pull | Feed-in Tariff for renewable electricity. Currently 15 c EUR/kWh for ocean energy |
| | Push | ADEME, 1125 m EUR (renewable energy and green chemistry). Specific call for ocean energy funds projects with 4–6 machines at min. generation of 2500 MWh per machine for 2 years. Eight projects have submitted proposals, selection finalised by end of 2014. Each project might receive 30 m EUR and benefits from a Feed-in Tariff of 17.3 c EUR/kWh. |
| Ireland | Pull | Feed-in Tariff for ocean energy of 0.26 c EUR/kWh (up to 30 MW) from 2016 |
| | Push | SEAI Prototype Development Fund, 26 m EUR |
| | | Ocean energy development budget will be increased by 16.8 m EUR to 26.3 m EUR by 2016, mainly for test centres |
| | | SEAI Sustainable RD&D programme, 3.5 m EUR |
| Portugal | Push | Fundo de Apoio à Inovação (FAI) for renewable energies, 76 m EUR total |
| Spain | Pull | Feed-in Tariff suspended for all renewables, replaced in 2014 by a scheme of a fixed annual investment bonus for existing installations |
| | Push | EVE, 3 m EUR scientific programme for ocean energy demonstration |
| Denmark | Pull | Maximum tariff of 8 c EUR/kWh (sum of market price and bonus) for ocean energy. |
| | Push | Energinet.dk, 2.4 m EUR for minor renewable energy technologies (e.g. PV, wave, biogasification) by ForskVE. In 2015 round, the programme for development and demonstration projects will provide about 13.4 m EUR of funds |
| Germany | Pull | Feed-in Tariff, 3.5–12.5 c EUR/kWh for ocean energy, depending on installed capacity |

*Sources:* [1,26–38].

while providing support to wave and emerging ocean energy technologies. The wide spectrum of mechanisms available allows policy makers and developers to match funding schemes with the current technology level.

### 3.3. Environmental and administrative issues

The nascent status of the ocean energy sector yields a number of unknowns with regards to the potential environmental impacts that ocean energy converters may have on the surrounding marine environment. The uncertainties in identifying and mitigating environmental and socio-economic impacts coupled with current licensing procedures, which were not implemented to assess ocean energy technologies, constitute one of the mayor barriers to ocean energy development, including:

- **Environmental issues:** Developers may face stringent and costly monitoring requirements, in particular in relation with the size of the project; additionally monitoring is often required before and after consent. Regulatory authorities often adopt a conservative approach by enforcing extensive monitoring requirements on developments, when unsure of potential impacts.

- **Administrative issues:** Procedures to obtain full consent are often lengthy, delaying the project development. Furthermore at EU level there is a lack of uniform procedures with regards to licensing and consenting.
- **Social acceptance issues:** Ocean energy deployments could experience significant delays and opposition from local communities if these are not correctly engaged.

It is likely that most of the above issues will progressively have lower relevance once increased knowledge on the subject will be accrued, devices are improved, and once regulating authorities become more familiar with ocean energy technologies and projects. Addressing in the short period the above issues should help reducing the inherent sense of risk perceived by developers. This can be achieved by designing mitigation measures to minimise or eliminate significant environmental impacts. A number of funded projects have been looking at addressing administrative bottlenecks, environmental uncertainties and social impacts of ocean energy converters [39].

### 3.4. Grid availability

One of the raising concerns for the ocean energy sector is the availability of grid in the proximity of proposed ocean energy projects. Often, remote areas lack suitable grid infrastructure and require either network upgrades or the construction of new network lines, whose costs may fall on the developers.

It has to be noted, however, that grid issues may not be critical in all markets. Countries such as France, Portugal, Spain and The Netherlands may have an advantage in developing ocean energy projects since grid infrastructure is available close to ocean energy resources along their coasts [2].

Different EU policies are pushing for the implementation of shallow charging regimes [40], where developers share the cost of new grid capacity with grid operators. However, the ocean energy sector faces the same challenges of the wind energy sector; by developing resource-based technologies, whilst most current grid infrastructure is currently built on availability and usage. The transition to an integrated European grid in the context of the implementation of the 2030 Climate and Energy Policy Framework will play an important role in defining renewables integration in the European energy system [41,42].

Another key aspect for the ocean energy sector is the issue of grid integration. In this context the adoption and development of grid-codes in line with the experience of the wind and offshore wind energy technologies would provide opportunities for concerted RD&D efforts between the two sectors [43]. Electrical and infrastructural costs account for about 10–15% of wind and ocean energy farms expenditure and the identification of mutual solutions to both availability and integration issues will

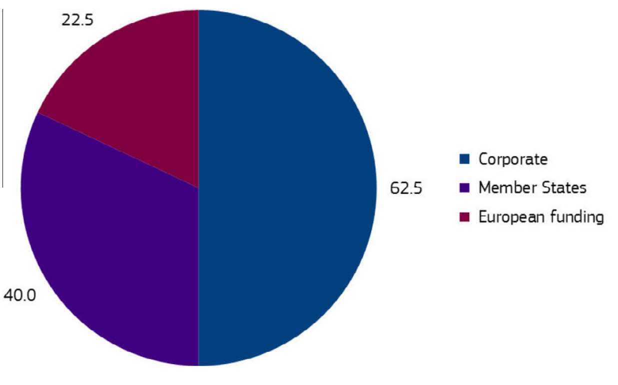


**Fig. 4.** Total RD&D investment in wave and tidal energy projects in 2011 in m EUR. *Source:* [19]. Full circles represent technology front-runners, hollow circles represent the general market maturity for each technology.

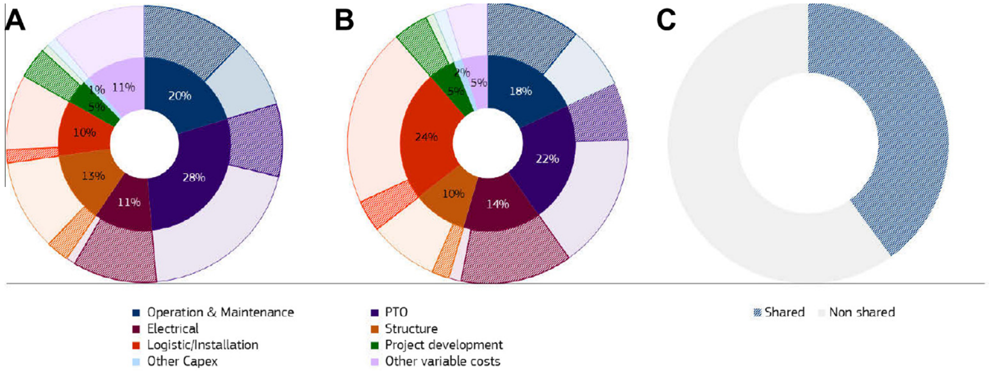


**Fig. 5.** Synergies between wave and tidal and offshore wind cost-components. (A) wind; (B) wave and tidal; (C) overall. *Source:* [25]. Dark shaded areas identify synergies between wind and ocean energy technologies specific cost-components.

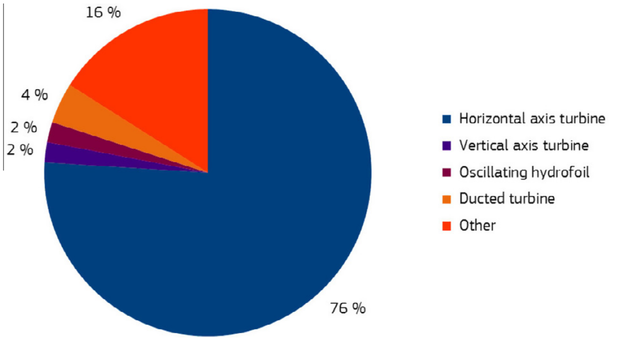


**Fig. 6.** Distribution of R&D efforts in tidal technology types. *Source:* [19].

provide a common avenue for the reduction of LCOE, and a pathway for R&D synergies in both sectors (Fig. 5).

## 4. Trends in tidal energy

Horizontal-axis turbines (HAT) represent the most common type of tidal energy designs; accounting for 76% of R&D efforts in the development of tidal devices worldwide (Fig. 6).

HATs represent also the class of devices that has sustained intensive open water testing and shows high technology readiness of devices. In the UK, since 2008 ocean energy technologies have fed more than 11,000 MWh of electricity to the grid since 2008, of which 10,250 MWh were generated by bottom-mounted horizontal-axis tidal turbines (Fig. 7) [44]. The technological progression of tidal energy technologies and has brought other key industrial players to the sector, notably Voith Hydro, Kawasaki Heavy Industries, Hyundai Heavy Industries, Tocardo and Schottel. They are involved in either technology development or adaptation of existing conversion technologies to second (floating) and third generation (multi-platform) tidal energy devices.

The tidal energy market is slowly shaping up. Over 100 tidal energy companies worldwide [45] have invested in the development of tidal energy technology. The EU accounts for more than 50% of tidal developers. Countries such as Canada, Australia and the USA also have strong representations, whilst increased activities are seen in eastern Asia (Fig. 8).

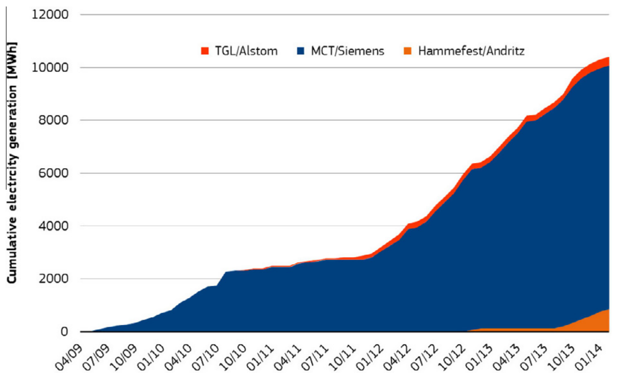


**Fig. 7.** Electricity generation from Tidal Energy Converters in the UK. *Source:* [42].

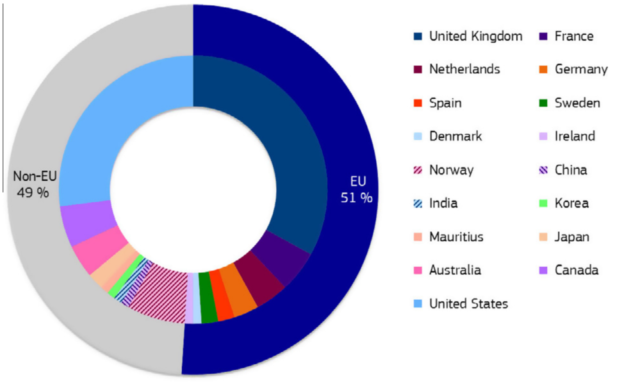


**Fig. 8.** Distribution of tidal companies in the world [45].

An overview of tidal energy developers whose technologies are at an advanced status of developments and are aiming to the deployment of single device or at development of pre-commercial or small commercial arrays is presented in Appendix A.

Over the past few years a wide number of tidal energy projects have been announced accounting for over 1500 MW of projected capacity in Europe [19]. However, only a small fraction of them has actually been commissioned and only the Meygen project has so far reached financial close. In the UK alone, the Crown Estate has leased 26 zones for tidal energy development in the UK accounting for over 1200 MW, with additional tidal demonstration zones announced in July 2014 [46], three of which in collaboration with local communities [46]. Five more sites are currently under construction in France, with expectation of devices being operational by 2016. Small size arrays have been announced for construction on dikes in the Netherlands in 2016. By 2018, Europe could see its tidal installed capacity increasing to about 57 MW, a significant step-forward for to the development of a tidal energy market (Fig. 9).

A key step towards the formation of the tidal energy market is the ability to attract and maintain active engagement with the supply chain, which could offer cost-reduction pathways through economies of scales. Table 3 presents an overview of identified suppliers of components and subcomponents for the tidal energy sector. Of particular relevance is the collaboration that is seen between developers and blades manufacturers, who work closely to assure design specification and fabrication requirements are met.

A correct estimate of the number of companies involved at any stage of the tidal energy supply chain is currently not possible. Many companies have announced developments in a particular area

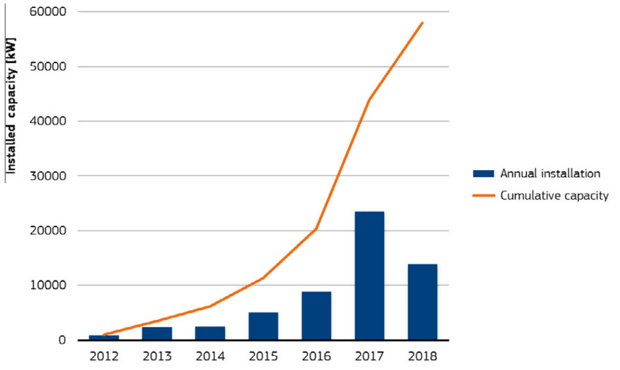


**Fig. 9.** Expected tidal developments until 2018.

**Table 3**
Identified suppliers for TEC.

| Developers | Blades | Bearings | Brakes | Shaft | Gearbox | Control | Generator | Electrical |
|---|---|---|---|---|---|---|---|---|
| Alstom/TGL | AEL | | | Invo-tech | Orbital2 Wikov | | In house | |
| Andritz Hydro/ Hammerfest | Gurit | | | Schottel | | | In house | Converteam |
| Atlantis R.C. | Norco Ltd | | Altra Industrial Motions | Schottel | David Brown | Schottel | ATB Morley | ABB |
| MCT/Siemens | AEL | NKE | | Invo-tech | Orbital2 Wikov | | In house | |
| Nova Innovation | Designcraft | | | | Siemens | | Siemens | |
| Ocean Flow | Designcraft | | James Fisher Defence | James Fisher Defence | James Fisher Defence | | | |
| Open Hydro | Norco Ltd | | | | | | In house | |
| Pulse Tidal | Designcraft | | Bosch Rexroth | Bosch Rexroth | Bosch Rexroth | Fraunhofer IWES | In house | Senergy Econnect |
| Schottel | Avantgarde Technologie | Wolfgang Preinfalk | | | | | In house | |
| ScotsRenewables | | | | | | MacArtney | In house | ABB |
| Tidal Energy Limited | Designcraft | | | | Siemens | | In house | General Electrics |

*Source:* information retrieved on company sites. Tenders may have changed following testing of components/R&D advancements.

of the sector but not disclosed the developers they are working with. Fig. 10 presents a composition of the tidal supply chain based on data from Syndicat des Energies Renouvelables (ENR) with regards to ocean energy. Currently, over 500 companies in Europe are involved in the various steps of the development of ocean energy.

As the sector expands and the tidal market picks up, it is likely that the supply chain will consolidate itself, thus providing further avenues for cost-reductions through economies of scale.

## 5. Trends in wave energy

Despite attracting wider interest and more investments than the tidal energy sector, wave energy technologies have not reached the same level of reliability and technological readiness of their tidal counterparts. For example, since 2008 in the UK wave energy feed 0.8 GWh of electricity to the grid, 8% of what tidal technologies have generated in the same period. One of the main issues affecting the

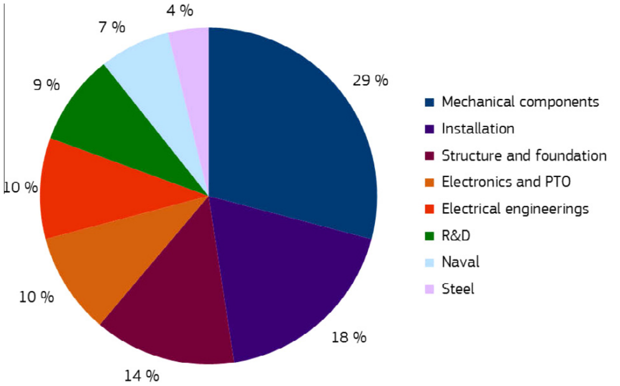


**Fig. 10.** Ocean energy supply chain breakdown in France in terms of number of companies. *Source:* [47].

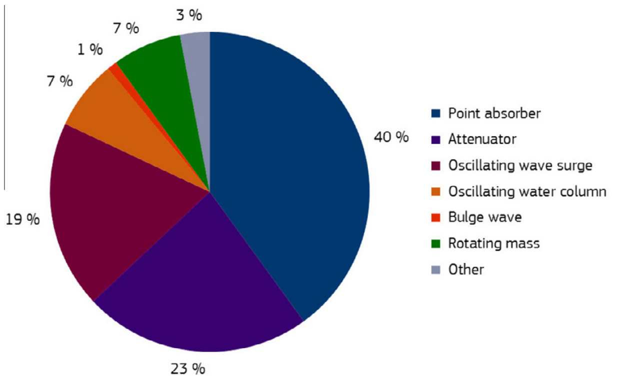


**Fig. 11.** Distribution of R&D efforts according to wave energy technology type. *Source:* [25].

development of wave energy is the lack of design consensus amongst the various devices. Three different device classes account for 82% of research efforts [20] (Fig. 11). The potential associated with wave energy worldwide, estimated to be around 28,000 TWh [26,28], has attracted over 170 developers to the sector [48]. These numbers confirm the global effort and interested in developing reliable wave energy technologies.

45% of wave energy developers are based within the EU, which also hosts the majority of wave energy infrastructure, however it shall be noticed that to date only a limited number of devices have reached full scale testing-phase or further. The JRC has identified 46 wave energy companies that have reached or are about to reach open-sea deployment of their technologies, which are presented in the Appendix B.

64% of wave energy devices are designed for offshore application (Fig. 13); however most of the installations to date have taken place within 10 km from shore (Fig. 14). In the summer of 2014, two WECs developed by Seatricity were deployed at the Wave Hub in South West of the UK [50], 16 km from shore. This deployment, yet to be grid-connected, represents the most distant installation of WECs from shore. The difficulty of installing wave energy technology offshore shows the sector still has to identify solutions related to the survivability and maintenance of the devices, especially in offshore environments.

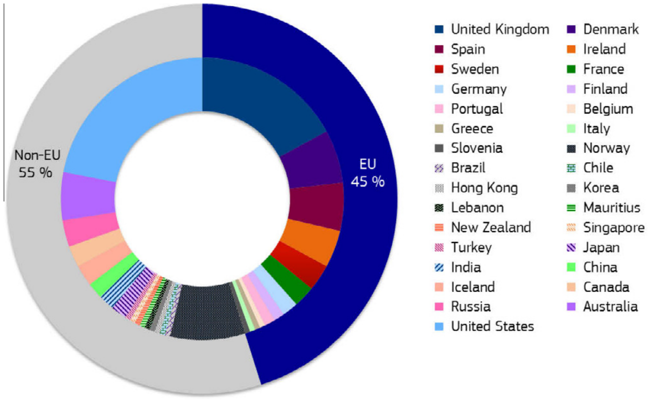


**Fig. 12.** Distribution of wave companies in the world. *Source:* [49].

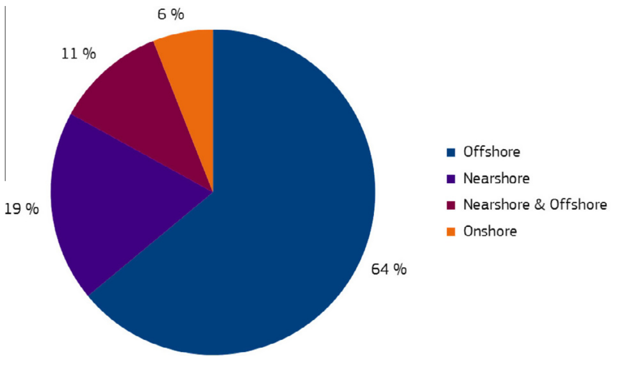


**Fig. 13.** Wave energy applications of current WECs. *Source:* [2].

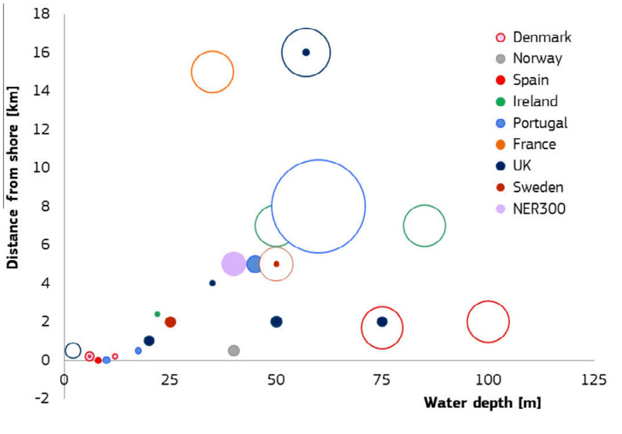


**Fig. 14.** Wave infrastructure in Europe. The size of the bubble refers to the capacity of installed project (full circle) or the maximum site capacity (hollow circle).

**Table 4**
Wave energy development and deployment projects receiving EU or national support.

| Project name | Capacity | Funding awarded | Funding body | Expected operation date |
|---|---|---|---|---|
| West Wave, Co. Clare, Ireland | 5 MW | 23.3 m EUR | NER 300/EU | 30/06/2018 |
| Swell Peniche, Portugal | 5.6 MW | 9.1 m EUR | NER 300/EU | 01/01/2018 |
| Pelamis & Aquamarine Power, Scotland | N/A | 13 m GBP | MCRF Wave First Array Support Programme | N/A |
| EMEC, Green Theme, Tension Technology International, Scotland | N/A | 4.8 m GBP | MRCF | N/A |
| Atlantic Marine Energy Test Site (AMETS), Belmullet, Ireland | 20 MW | 24 m EUR | Sustainable Energy Authority of Ireland (SEAI) | T.B.A. |
| Biscay Marine Energy Platform (BIMEP), Armintza, Spain | 20 MW | 20 m EUR (infrastructure) | Ente Vasco de la Energía (EVE), Spanish Energy Agency | Operational |
| EMEC, Orkney, UK | 6 grid connected berths | 36 m GBP | Scottish Government, Highlands and Islands Enterprise, The Carbon Trust, UK Government, Scottish Enterprise, Orkney Islands Council. | Operational |
| OCEAN PLUG, Leira, Portugal | 80 MW (up to 250 MW) | N/A | Redes Energéticas Nacionais (REN) | In progress |
| Oceanic Platform of the Canary Islands (PLOCAN), Canary Islands, Spain | 10 MW (up to 100 MW) | N/A | Spanish Government, Regional Government of the Canary Islands. | Operational |
| Site d' Expérimentation en Mer pour la Récupération de l'Energie des Vagues (SEM-REV), Le Croisic, France | 8 MW | 13.26 m EUR | Ecole Centrale de Nante, Pays de la Loire, Loire-Atlantique | Operational |
| Wave Hub, Hayle, UK | 20 MW | 42 m GBP | DECC, Southwest Regional Development Agency. | Operational |

The gap between wave and tidal energy technologies is also reflected in the inability of wave energy developers to deploy their technologies and secure array demonstration funds. A number of initiatives have been proposed by national and local governments to support the development of wave energy technologies; including the development of dedicated facilities and sites for testing of wave energy converters. In Europe alone, 13 of these sites have been built through local governments funds [51]. In Australia and in the United States specific mechanisms have been implement to support wave energy research, development, and demonstration (RD&D). The Marine Hydrokinetic System

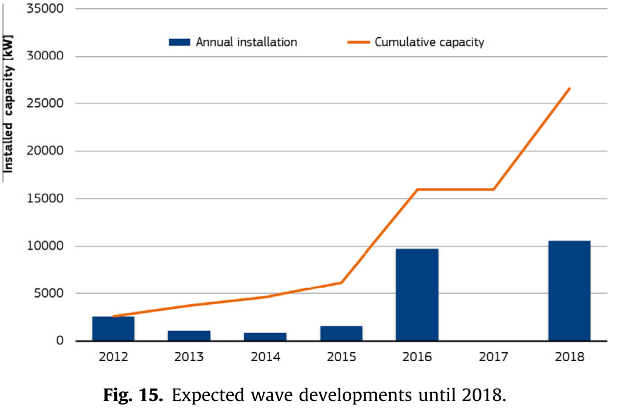


**Fig. 15.** Expected wave developments until 2018.

Performance Advancement, launched in 2013 by the US Department of Energy (DOE), addressed specifically PTOs, control and structural design of wave energy converters [52].

ARENA, the Australian Renewable Energy Agency has provided 110 m AUD in RD&D funds for wave energy. In order to ensure that the type of funding matches the technology maturity, Arena introduced the Commercial Readiness Index (CRI). The CRIs consist of a series of indicators and targets matching the maturity of technology at high TRLs. The aim is of this initiative is to reduce the risk for developers and funders investing in emerging energy technologies, through the provision of specific funding mechanisms for each stage of the development chain.

The use of such instruments may prove beneficial in identifying the correct support scheme for wave energy. In the UK, the Wave First Array Support programme was made available when it was clear the leading wave energy technologies would have not been able to meet the requirements for MEAD funding. This programme aims to facilitate the deployment of wave energy arrays by the 2016–2018 timeframe [53], by focussing specifically on wave energy technology development.

Currently, two wave energy projects are schedule to receive funds from the second NER300 call, the West Wave project which was awarded 23 m EUR, and the SWELL project, a 5.6 MW wave energy array project off the coast of Portugal which will receive 9.1 m EUR. It should be noted that the WestWave project withdrew from the funding awarded during the first call of NER300, since none of the selected wave energy technologies was deemed to be ready for installation by 2016 and to generated the required MWh to match funding requirements. An overview of European and national support schemes for wave energy is presented in Table 4.

It is critical for the wave energy sector to identify and ensure long-term reliability and survivability of the devices. Since 2009 more than 100 wave energy projects were announced in Europe alone, for a total installed capacity of 1200 MW, however projects for over 770 MW have already been aborted. Nevertheless, the sector is expected to reach 26 MW of installed capacity in Europe by 2018 (Fig. 15), with deployments consisting mainly of single unit and array demonstration projects.

The picture of the supply chain engagement for leading wave energy developers looks much more scattered compared to the one identified for the tidal sector, as shown in Table 5. A step towards design convergence is the collaboration started by Aquamarine Power, Albatern and Carnegie to identify a common PTO system with Bosch Rexroth.

**Table 5**
Identified suppliers for WECs according to component and service.

| Company | Fabrication | PTO & generator | Electrical & automation | Bearings | Marine operations | Hydraulic components | Coating | Diagnostic |
|---|---|---|---|---|---|---|---|---|
| 40South Energy | | | ABB | | | | | |
| Albatern | Zeus Engineering, Purepipe | Bosch Rexroth | | | Mallaig Marine | Mallaig Marine | | |
| Aquamarine Power | Burntisland Fabrications | Bosch Rexroth | ABB | Hutchinson | Fugro Seacore | Hunger Hydraulics | | BAE Systems |
| AW Energy | | | Metso | | | | Hempel | |
| Carnegie | | Bosch Rexroth | | Hutchinson | | | | |
| Fred Olsen Ltd | A&P Falmouth, Supacat | Siemens | | | SeaRoc | | | |
| Langlee Wave Power | Repnaval | | | | | | | |
| Pelamis Wave Power | Barnshaws | | KTR Couplings | Schaeffler | | | | |
| Seatricity | A&P Falmouth | | | | | | | |
| Wello OY | Riga Shipyard | The Switch | Veo | Schaeffler | | Hydac, Seaproof Systems | | |

## 6. Conclusion

Despite a high potential associated with ocean energy worldwide, the electricity production from ocean energy is negligible. Tidal and wave energy are currently the most advanced types of ocean energy technologies, but have not yet achieved the level of reliability, feasibility and survivability of other mature renewable technologies to become a viable energy source. In order to promote the development of ocean energy technologies, concerted efforts are needed to overcome the existing barriers.

The development of ocean energy technologies is hindered by four main bottlenecks: technology development, finance and markets, environmental and administrative issues and grid availability. At EU and global level a number of initiatives are providing ocean energy developers different platforms to overcome existing barriers. Concerted efforts by industry, academia along with the support of policy makers will be fundamental to identify common solutions that would allow the establishment of the ocean energy market.

In the EU, existing and available mechanisms appear to be adequate to sustain the growth of the sector, though it is essential they can be tailored to the needs of the various technologies and their status. The implementation of technology-specific support mechanisms and achievable KPIs could provide further scope for the progress of ocean energy technology. The harmonisation of policy mechanisms and consenting process at MS level is expected to help the sector overcoming administrative and environmental issues; while the shift towards an integrated European Energy system may provide the required support in overcoming infrastructural barriers with regards to grid availability.

From a policy standpoint, 2014 was a key year for the sector with the publication of the Blue Energy Communication, followed up by the launch of the Ocean Energy Forum and the European Technology and Innovation Platform for Ocean Energy). These initiatives provide a framework for the sector to address common issues and identify common solutions towards the commercialisation of its technologies. In addition, the number of ocean energy arrays supported by the EU NER 300 programme expected to be operational by 2018 has risen to five.

On the other hand, the slow technological progress combined with difficulties in attracting funds and financing for first of a kind array demonstration projects is hindering investors' confidence in the sector. The high risk associated with projects coupled with delays in market-formation have forced key developers and OEM to either downsize or withdraw their interest in the developing ocean energy technologies. Furthermore, only about 170 MW of ocean energy are expected to be operational globally by 2020.

The ocean energy market is still in its infancy, and its creation requires developers to prove the reliability of their technologies by increasing operational hours and the development of demonstration arrays. Currently 30 tidal companies and 45 wave energy companies are at an advanced stage of development. An increasing number of technologies are nearing pre-commercial array demonstration. The Meygen is the first large tidal energy project that has reached financial close and it is expected to be operational by 2016. Wave energy demonstration arrays are currently being developed in Australia and Europe. Taking into account the existing pipeline of ocean energy projects which have been awarded funds, Europe could see up to about 57 MW of tidal and 26 MW of wave energy capacity installed operational by 2020.

Europe represents the main hub for R&D on ocean energy technologies. A number of policies and mechanisms have been put in place to support the development of ocean energy, both at EU and MS level. The successful establishment of the ocean energy market requires that incentive policies and strategies are matched to the actual level of technology maturity, and that lessons learned are shared among developers and policymakers in order to remove administrative barriers and streamline consenting.

## Appendix A. Identified tidal energy developers

| Company name | Model | Operational testing | Country | Website |
|---|---|---|---|---|
| Alstom Hydro/Tidal Generation Limited | TGL series | Full-scale | France/UK | www.alstom.com/power/renewables/ocean-energy/tidal-energy |
| Andritz Hydro Hammerfest | HS series | Full-scale | Norway/Austria | www.hammerfeststrom.com |
| Aqua Energy Solutions | AES tidal devices | Part-scale | Norway | www.aquaenergy.no |
| Atlantis Resources Corporation | AN series, AR series, AS series | Full-scale | Singapore/UK | www.atlantisresourcesltd.com |
| BioPower System Pty Ltd | bioStream | Full-scale | Australia | www.biopowersystems.com |
| Bluewater | BlueTEC | Part-scale | Netherlands | www.bluewater.com/new-energy/tidal-energy/ |
| Clean Current Power Systems | Clean Current Turbine | Full-scale | Canada | www.cleancurrent.com |
| Deepwater Energy BV | Oryon Watermill | Part-scale | Netherlands | www.deepwater-energy.com |
| EEL Energy | EEL Tidal Energy Converter | Small-scale | France | www.eel-energy.fr/en |
| Elemental Energy Technologies | SeaUrchin | Small-scale | Australia | www.eetmarine.com |
| Flumill | Flumill | Part-scale | Norway | www.flumill.com |
| Hydra Tidal Straum AS | Hydra tidal | Part-scale | Norway | www.hydratidal.info |
| Hyundai Heavy Industries | | Part-scale | South Korea | www.hyundaiheavy.com/news/view?idx=332 |
| IHC Tidal Energy/Tocardo[a] | OceanMill | Part-scale | Netherlands | www.ihctidalenergy.com |
| Kawasaki Heavy Industries Ltd | | Full-scale | South Korea | www.khi.co.jp/english/news/detail/20111019_1 |
| Marine Current Turbines | SeaFlow, SeaGen | Full-scale | UK/Germany | www.marineturbines.com |
| Magallanes Renovables | Atir | Part-scale | Spain | www.magallanesrenovables.com |
| Minesto | Deep Green | Part-scale | Sweden | www.minesto.com |
| Nautricity | CoRMaT | Full-scale | UK | www.nautricity.com |
| New Energy Corporation | EnCurrent Turbine | | Canada | www.newenergycorp.ca |
| Nova Innovation | Nova-I | Part-scale | UK | www.novainnovation.co.uk |
| Ocean Flow Energy | Evopod | Small-scale | UK | www.oceanflowenergy.com |
| Ocean Renewable Power Company | TidGen | Small-scale | USA | www.orpc.co |
| Oceana Energy Company | Oceana | Small-scale | USA | www.oceanaenergy.com |

**Appendix A.** (*continued*)

| Company name | Model | Operational testing | Country | Website |
|---|---|---|---|---|
| OpenHydro (DCNS) | Open Centre Turbine | Full-scale | Ireland/France | www.openhydro.com |
| Sabella SAS | Sabella D03 | Part-scale | France | www.sabella.fr |
| Schottel Group | STG series | Full-scale | Germany | www.schottel.de |
| Scotrenewables | SR series | Part-scale | UK | www.scotrenewables.com |
| Tidal Energy Ltd | DeltaStream | Part-scale | UK | www.tidalenergyltd.com |
| TidalStream Limited | Plat-O | Part-scale | UK | www.tidalstream.co.uk |
| Tidalys | Electrimar1800, 4200 | Part-scale | France | www.tidalys.com |
| Tocardo Tidal Turbines | T series | Full-scale | Netherlands | www.tocardo.com |
| Uppsala University: The Ångström Laboratory | | Small-scale | Sweden | |
| Verdant Power | Free Flow System | Full-scale | USA | www.verdantpower.com |
| Voith Hydro | HyTide | Full-scale | Germany | http://www.voith.com/en/products-services/hydro-power-377.html |
| Vortex Hydro Energy | VIVACE | Small-scale | USA | http://www.vortexhydroenergy.com |

[a] Tocardo acquired IHC Tidal in November 2014.

## Appendix B. Identified wave energy developers

| Company name | Model | Operational testing | Country | Website |
|---|---|---|---|---|
| 40South Energy | R115, Y series, D series | Full-scale | Italy/UK | www.40southenergy.com |
| Albatern | SQUID | Part-scale | UK | http://albatern.co.uk/ |
| AquaGen Technologies | SurgeDrive | Small-scale | Australia | www.aquagen.com.au |
| Aquamarine Power | Oyster | Full-scale | UK | www.aquamarinepower.com |
| Atargis Energy | | Small-scale | USA | www.atargis.com |
| AW Energy | WaveRoller | Full-scale | Finland | www.aw-energy.com |
| AWS Ocean Energy | AWS-III, Archimedes Wave Swing | Full-scale | UK | www.awsocean.com |
| BioPower Systems Pty Ltd | bioWave | Small-scale | Australia | www.biopowersystems.com |
| Bombora WavePower | Bombora WEC | Small-scale | Australia | http://www.bomborawavepower.com.au/ |
| Carnegie Wave Energy Ltd | CETO | Full-scale | Australia | www.carnegiewave.com |
| Columbia Power Technologies | Manta, SeaRay | Part-scale | USA | www.columbiapwr.com |
| COPPE Subsea Technology Laboratory | | Part-scale | Brazil | www.coppenario20.coppe.ufrj.br/?p=805 |

(*continued on next page*)

**Appendix B.** (*continued*)

| Company name | Model | Operational testing | Country | Website |
|---|---|---|---|---|
| DexaWave A/S | DexaWave | Small-scale | Denmark | www.dexawave.com |
| Eco Wave Power | Wave Clapper, Power Wing | Part-scale | Israel | www.ecowavepower.com |
| Floating Power Plant AS | | Part-scale | Denmark | www.floatingpowerplant.com |
| Fred Olsen Ltd | FO3, Bolt, Bolt 2 Lifesaver | Full-scale | Norway | www.fredolsen-renewables.com |
| Intentium AS | ISWEC, IOWEC | Full-scale | Norway | www.intentium.com/ |
| Kymaner | Kymanos | Part-scale | Portugal | http://www.kymaner.com/ |
| Langlee Wave Power | Rubusto | Full-scale | Norway | www.langlee.no |
| LEANCON Wave Energy | MAWEC | Small-scale | Denmark | www.leancon.com/ |
| Neptune Wave Power | Neptune WECD | Part-scale | USA | http://www.neptunewavepower.com/ |
| Ocean Energy Ltd | OEBuoy | Part-scale | Ireland | www.oceanenergy.ie |
| Ocean Harvesting Technologies | | Full-scale | Sweden | http://www.oceanharvesting.com/ |
| Ocean Power Technologies | PowerBuoy | Full-scale | USA | www.oceanpowertechnologies.com |
| Oceantec | Oceantec WEC | Small-scale | Spain | www.oceantecenergy.com |
| Offshore Wave Energy Ltd (OWEL) | OWEL WEC | Small-scale | UK | www.owel.co.uk |
| Oscilla Power | Wave Energy Harvester | Small-scale | USA | www.oscillapower.com |
| Pelamis Wave Power[a] | Pelamis | Full-scale | UK | www.pelamiswave.com |
| Perpetuwave | Wave Harvester | Part-scale | Australia | http://www.perpetuwavepower.com/ |
| Pico Plant EU Consortium | Pico Plant OWC | Full-scale | | |
| RESEN Waves | LOPF Buoy | Small-scale | Denmark | http://www.resen.dk/resen_standard.asp?pageid=120 |
| Resolute Marine Energy Inc. | SurgeWEC | Full-scale | USA | www.resolute-marine-energy.com |
| SDE Energy | Sea Wave Power Plants | Full-scale | Israel | http://www.sdeglobal.com/ |
| Seabased AB | Seabased | Full-scale | Sweden | www.seabased.com |
| Seatricity | Oceanus | Full-scale | UK | www.seatricity.net |
| Spindrift Energy | Spindrift | Small-scale | USA | http://www.spindriftenergy.com/ |
| Trident Energy Ltd | PowerPod | Full-scale | UK | www.tridentenergy.co.uk |
| Voith Hydro Wavegen | Limpet OWC, Mutriku OWC | Full-scale | | |
| Wave Dragon | Wave Dragon | Part-scale | Denmark | http://www.wavedragon.net/ |
| Wave Energy Technology New Zealand (WET-NZ)[b] | WET-NZ | Part-scale | New Zealand | www.waveenergy.co.nz |
| WaveRider Energy | WaveRider Platform | Part-scale | Australia | www.waveriderenergy.com.au |
| WaveStar Energy | WaveStar | Part-scale | Denmark | www.wavestarenergy.com |

**Appendix B.** (*continued*)

| Company name | Model | Operational testing | Country | Website |
|---|---|---|---|---|
| Wedge Global | | Part-scale | Spain | www.wedgeglobal.com |
| Wello OY | Penguin | Full-scale | Finland | www.wello.fi |
| WePTO | WePTO WEC | Part-scale | Denmark | www.weptos.com |

[a] Pelamis filed for administration in November 2014.
[b] WET-NZ sold its technology to a US-based company in 2014.

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