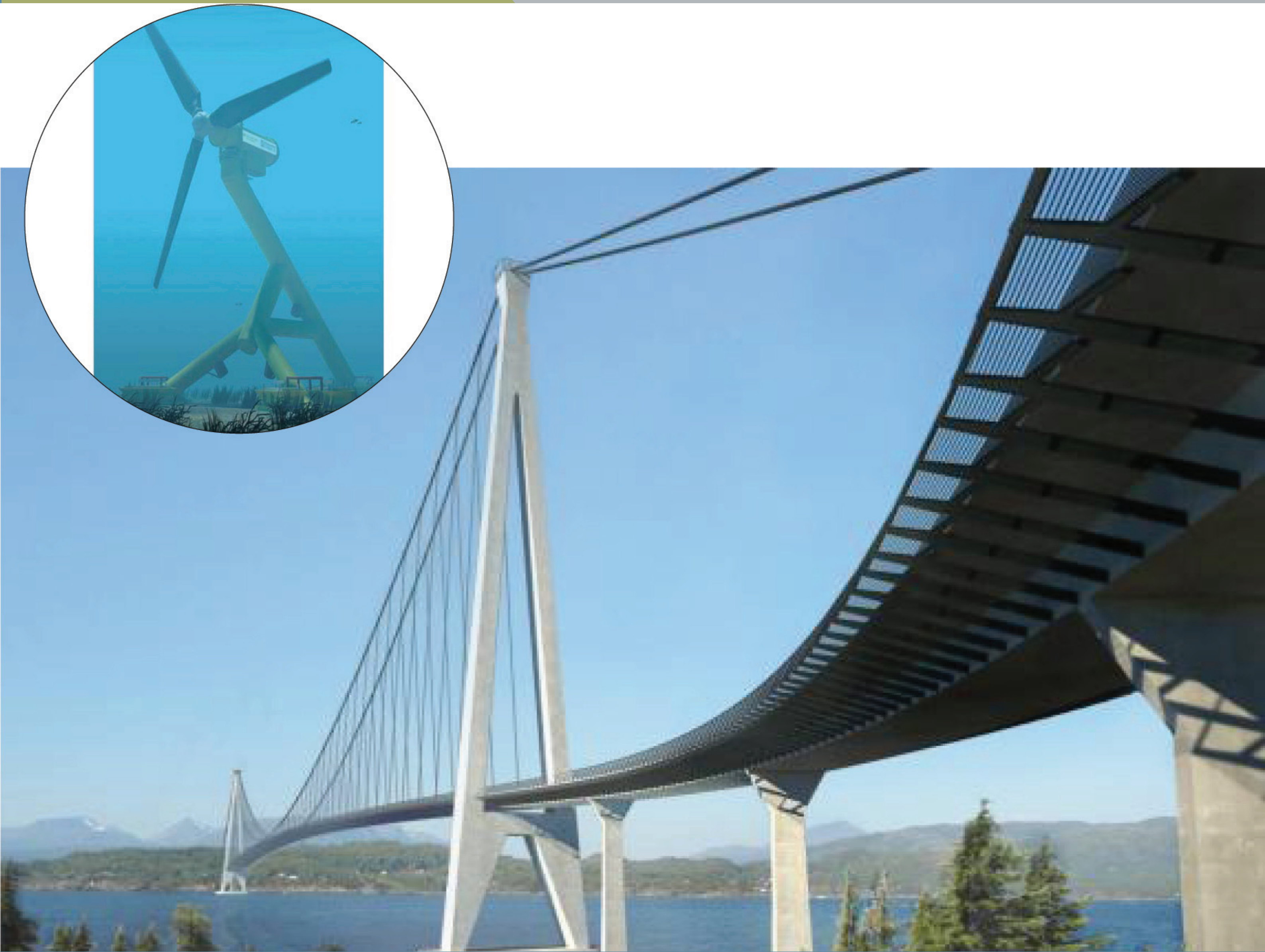
Statens vegvesen

Technology survey for renewable energy Integrated to bridge constructions

Wave and tidal energy

Statens vegvesens rapporter

Nr. 109



SP Technical Research Institute of Sweden

April 2012

Statens vegvesens rapporter

NPRA reports
Norwegian Public Roads Administration

Tittel
Technology survey for renewable energy Integrated to bridge constructions

Title
Technology survey for renewable energy Integrated to bridge constructions

Undertittel
Wave and tidal energy

Subtitle
Wave and tidal energy

Forfatter
Daniel Vennetti, SP

Author
Daniel Vennetti, SP

Avdeling
Trafikksikkerhet, miljø- og teknologiavdelingen

Department
Traffic Safety, Environment and Technology

Seksjon

Section

Prosjektnummer
603360

Project number
603360

Rapportnummer
Nr. 109

Report number
No. 109

Prosjektleder
Hoseini Mohammed

Project manager
Hoseini Mohammed

Godkjent av

Approved by

Emneord

Key words

Sammendrag

Summary

Antall sider 286

Dato April 2012

Pages 286

Date April 2012

Wave and Tidal Energy Technology Survey for Ferry Free E39 Project

Daniel Vennetti

SP Technical Research Institute of Sweden

SP Structural and Solid Mechanics

SP Arbetsrapport :2012:06

Wave and Tidal Energy Technology Survey for Ferry Free E39 Project

Daniel Vennetti

SP Sveriges Tekniska Forskningsinstitut
SP Technical Research Institute of Sweden

SP Arbetsrapport :2012:06
ISBN
ISSN 0284-5172
Borås 2012-04-05

Table of contents

Executive summary

E39 is a road that is located on the west coast of Norway and extends from Kristiansand in the south to Trondheim in the north. Currently, a number of ferry crossings are required to traverse its entire length. The Transport Ministry has given a mandate for the project "Ferry Free E39" to assess the technological solutions for the crossing of eight large fjords without ferries. The fjords crossings range from 1.5 km to 25 km in length and have depths up to 1300 m. Proposed solutions for the crossings that are under consideration consist of suspension bridges, floating bridges and submerged floating tunnels. Part of the project is to consider how the construction of the crossings can be combined with devices that produce energy from waves, tides, wind and the sun. The idea is that, by using the bridge construction as part of the facility, the costs of the renewable energy power plants could be reduced and therefore be more competitive.

SP Technical Research Institute of Sweden has been commissioned by the Norwegian Public Roads Administration to perform a technology survey and generate a summary of the current state of the art wave and tidal energy conversion technologies. Requests for information were sent to the majority of the active developers in order to obtain the most up to date information about the current technology status, performance data and conditions of functionality for each of the devices. The thoughts behind the questions asked in the requests for information and the results of this technology survey are presented herein.

Additionally, SP has been commissioned to make rough estimations of the potential energy that could be obtained from each fjord crossing by employing wave and tidal energy conversion technologies and to recommend the most suitable technology for integration with each fjord crossing concept. The methods behind the estimations of potential energy from each crossing and the background for the recommendations that are made are presented herein.

Unfortunately, a lack of tidal and wave energy resource data at the fjord crossing locations made it impossible to utilize the detailed calculation method that was described and a simplified calculation method was used to calculate rough estimates of the energy potential from the different devices. When the estimates were compared to previous studies it showed that the estimates based on the simplified approach were non-conservative. Source of non-conservatism in the calculations were discussed and it was concluded that the next stage of the study should concentrate on obtaining reliable data about the tidal and wave energy resources for the different fjord crossing locations. The data should be obtained over a significant period of time to ensure that the effects of seasonal variations in the resources are captured.

Once tidal and wave resources data is available, more realistic calculations of the potential energy production can be completed. At that point, comparisons of the performance of the difference technologies can be made.

From that point, more detailed studies should be undertaken where the concepts for combining the devices with the bridging technologies are optimized. This optimization should include actions such as loads analysis, structural strength

calculations, reliability and fatigue performance evaluations and detailed cost estimates.

1 Introduction

E39 is a road that is located on the west coast of Norway and extends from Kristiansand in the south to Trondheim in the north. Currently, a number of ferry crossings are required to traverse its entire length. The Transport Ministry has given a mandate for the project “Ferry Free E39” to assess the technological solutions for the crossing of eight large fjords without ferries. The fjords crossings range from 1.5 km to 25 km in length and have depths up to 1300 m. Proposed solutions for the crossings that are under consideration consist of suspension bridges, floating bridges and submerged floating tunnels. Part of the project is to consider how the construction of the crossings can be combined with devices that produce energy from waves, tides, wind and the sun. The idea is that, by using the bridge construction as part of the facility, the costs of the renewable energy power plants could be reduced and therefore be more competitive.

SP Technical Research Institute of Sweden has been commissioned by the Norwegian Public Roads Administration to perform a technology survey and generate a summary of the current state of the art wave, tidal, wind and solar energy conversion technologies. For the wave and tidal energy conversion technologies, requests for information were sent to the majority of the active developers in order to obtain the most up to date information about the current technology status, performance data and conditions of functionality for each of the devices. The thoughts behind the questions asked in the requests for information and the results of the technology survey for the wave and tidal energy conversion technologies are presented herein.

Additionally, SP has been commissioned to make rough estimations of the potential energy that could be obtained from each fjord crossing by employing wave, tidal, wind and solar energy conversion technologies and to recommend the most suitable technology for integration with each fjord crossing concept. The methods behind the estimations of potential energy for the wave and tidal energy conversion devices and the background for the recommendations that are made are presented herein.

2 Energy from the tides

2.1 How tides are generated

Tidal energy is a unique form of renewable energy. While other renewable energies are either directly or indirectly derived from solar energy, tidal energy is generated by the orbital characteristics of the Earth-Moon-Sun system [1]. The gravitational attractions between the Earth, the Sun and the Moon and the orbital nature of the system cause the ocean to bulge in different locations on the Earth at different times. As these bulges in the ocean rotate around the Earth, the water level seen from a specific location will rise and fall [2]. The main periods of the tides are called the diurnal (~24 hours) and the semidiurnal (12 hours 25 min) [3]. Throughout the year, the relative position of the two planets and the sun changes, causing the magnitude of the tides to vary. When the gravitational effects of the Sun and Moon are acting in the same direction, this is referred to as a spring tide and the difference in water height between high tide and low tide is above average. When the gravitational effects of the Sun and Moon are separated by 90°, this is referred to as a neap tide, and the tidal conditions are less extreme. A figure showing the types of tides caused by the relative location of the Earth, Moon and Sun is shown as *Figure 1*.

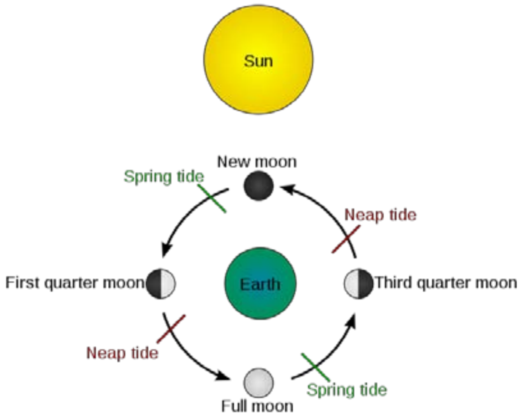


Figure 1 Tidal variation schematic.

The change in water height due to this rising and falling motion is referred to as tidal range. The rising and falling movement of the water also results in horizontal water motions which are called tidal currents. Because the tides are a result of the periodic variations of the Earth-Moon-Sun system, the tidal energy is more predictable than other renewable energy sources. Because generation and consumption across the electrical grid must be constantly balanced, this predictability is seen as a major advantage of tidal energy when compared to other renewable energy sources.

2.2 Tidal range energy conversion

The idea of extracting energy from the tidal range has existed for many centuries. It is documented that farmers in the middle ages (1200-1500 AD) would capture waters in mill ponds as the tides rose and use this stored potential energy to run tide mills as the tide level dropped [4]. It is even suggested that people may have been using tide mills as far back as Roman times [5]. An image of a more modern tidal mill is shown as *Figure 2*.

Large scale utilization of tidal range energy to generate electricity was first accomplished in 1966 by La Rance power facility near St. Malo in Brittany, France. This power station consists of a retaining basin, a barrage and sluices. The plant produces electricity in both ebb and flood flows using twenty-four turbines. The plant has a peak generating capacity of 240 MW and annually produces approximately 480 GWh to France's national electricity grid [7]. The global tidal energy range potential is estimated at 3 TW of which 1 TW is available in relatively shallow waters [3].

Despite the fact that there is such a great energy potential from the tidal range and the fact that La Rance has been successfully operated for over four decades, there have been very few major tidal barrages built.

Figure 2 Tidal mill at Olhão, Portugal [6].

One reason for this is the limited number of sites that have a significant tidal range. The tidal range of a particular location is largely affected by the shape of the shoreline and ocean floor. Features, such as estuaries, can also have a significant impact on the tidal range. While some locations such as the Bay of Fundy in Canada, where the height of the tide can reach 16 m, possess significant tidal range resources, the average tidal range of all oceans around the globe is 1 m [8]. With a significant tidal range required for a tidal barrage to be considered viable, the global number of potential sites is rather limited.

Another negative aspect of the tidal barrage is the potential for disturbance in the electrical grid control that can be associated with the large variation in the energy generation. During neap tides at La Rance power facility about 80,000 MWh/day is generated, while during an equinoctial spring tide 1,450,000 MWh/day are generated [1].

One more reason why so few tidal barrages have been built is the high construction costs associated with such structures. Because tidal barrages require large quantities of materials to be able to withstand the loads created by storing significant amounts of water, it is often times not economically viable to build these types of structures.

However, possibly the greatest disadvantage of tidal barrages is the potential for negative environmental impacts [7]. When a dam is built across an estuary, the currents into and out of the area inherently change which can have an effect on the natural balance within the estuary. As a result of all of these negative aspects, by the early 1990s much of the focus for extracting the energy from the tides shifted from tidal range conversion technologies to tidal current conversion technologies [4].

2.3 Tidal current energy conversion

Technologies that convert the kinetic tidal current energy are referred to as tidal in-stream conversion (TISEC) devices [9], marine current energy converters (MCECs) [10] or marine current turbines.

These types of devices were first conceived in the 1970s during the oil crisis [11]. Because they do not incorporate tidal barrages, they have been shown to have far less negative impacts on the local environment than the tidal range energy conversion devices [12]. While there is a broad range of concepts at this point, many of the designs are very similar to the wind turbine. Because the density of water is over 800 times greater than that of air, the power intensity in water currents is much higher than that of airflows. This means that a water current turbine can be built much smaller than a wind turbine to get the same power output, or that the water speeds can be significantly slower than wind speeds while generating the same amount of power for a similarly sized device. The optimum current speed for most technologies is between 1.5-3.5 m/s [13].

Because there are many sites globally with currents in the optimum range for these technologies, recent studies have indicated that marine currents could potentially supply a significant fraction of the future global energy needs. In Europe alone, the potential for MCECs is estimated to exceed 12,000 MW of installed capacity [3].

In two studies of the Norwegian coast, rough estimates of the technical tidal current energy resources have been calculated. The technical resource takes into account the amount of kinetic energy that can be extracted without creating a negative ecological impact or a reduction in the current speed (often referred to as the significant impact factor (SIF) [14]. The studies estimated the annual technical resource in Norway to be between 0.55 TWh to greater than 1 TWh [15] [16]. The broad range is largely due to the uncertainty in the SIF. Both studies also addressed Norway’s economical tidal current energy resource, which takes into account the fact that there may be technical or economic factors that would limit the site availability. The annual estimations for the economical resource were between well below 1 TWh to 1 TWh [15][16]. These estimates take into account Norway’s total economical tidal current energy resource and are therefore expected to be greater than the energy potential from just the fjord crossing locations of the Ferry Free E39 project.

3 Tidal in-stream conversion technology request for information

Because the tidal in-stream conversion industry is still in its infancy, it is in a constant state of change. Because many developers are using all of their available time and resources for further developing their technologies, much of the most up to date information is not available in published literature or even on homepages. With that in mind, it was decided that the best way of ensuring that the most relevant information was obtained from each technology developer was to send out a request for information (RFI). This method has proved to be an effective way of obtaining relevant information and to be able to form contacts with the actual tidal in-stream conversion technology developers [9].

The contacts that were made through the RFI process could also be used to inform the technology developers, stakeholders and research groups about the upcoming workshop/conference.

The RFI questions were formulated in an attempt to gain concise and relevant information which can be broken up into five basic categories: general information, device classification, technology status, operational characteristics, and relevance to the Ferry Free E39 project.

In the RFI it was stated that if any of the requested information was currently unavailable that the technology provider could simply state that in their reply. A sample reply was also generated for a fictional device in an attempt to give some guidance as to the desired style and format of the responses. The RFI that was sent to the TISEC device developers and the sample reply are included as *Appendix 1*.

3.1 General information

The general information questions were generated in large part to ensure that we have all of the necessary information to be able to distinguish the different technologies from one another and to ensure that we have appropriate ways to find information about the developer and technology in the future. The requested general information is as follows: company name, country, web address, technology name, figures/photographs of the device.

3.2 Device classification

Unlike many mature industries, the TISEC industry has not converged to a narrow band of solutions. Currently the range of solutions is extremely broad and there are new patents being granted all the time for novel approaches to solving the challenge of converting tidal current energy into something useful. With that in mind, it is extremely important to gain enough information about the design of the devices so that we can make relevant comparisons based on a classification scheme. The following sections describe the RFI questions that are meant to gain information about the classification of the devices.

3.2.1 General device classification information

The general device classification questions allowed the developer to discuss the unique idea behind their technology. The developer was asked to briefly explain the features and design principle of their technology. Additionally, information about the power train type and whether or not power was generated during ebb (when water height is decreasing) and flood (when water height is increasing) flows was requested of the developer.

3.2.2 Device type

While there is an extremely broad range of solutions, there are four basic design principles that many technology providers have utilized [17]. In the RFI, the developers were asked to identify if their device utilized one of those four basic design principles, or if it was a novel design. The four basic design principles are shown in *Figure 3* through *Figure 6*.

The first common design principle is the horizontal axis turbine, or axial flow turbine. These devices are very similar to typical wind turbines. The flow moves parallel to the axis of the turbine and energy from the flowing water is converted to rotation of the turbine as the water passes the blades. *Figure 3* shows a typical horizontal axis turbine.

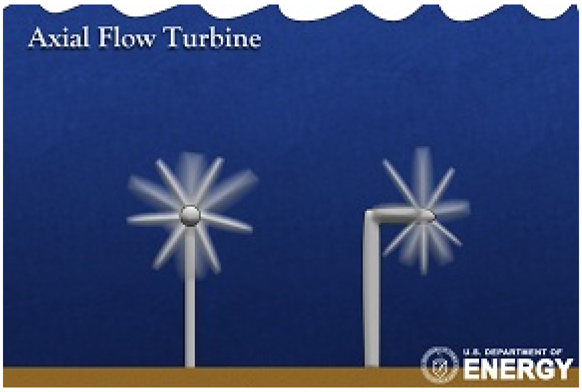


Figure 3 Horizontal axis or axial flow turbine design principle [18].

The second common design principle is the cross-axis or cross flow turbine. For these devices, the flow moves perpendicular to the axis of the turbine. The kinetic energy from the water is again converted to rotation of the turbine as the water passes the blades. This design type encompasses devices where the turbine axis is mounted both vertically and horizontally. The horizontal axis cross-axis turbine can even be used in shallow water. The cross-axis design principle is shown in *Figure 4*.

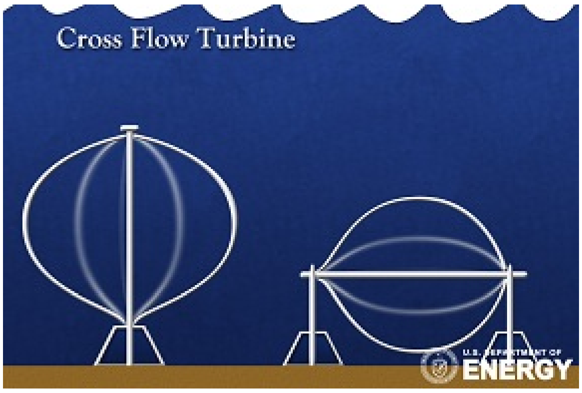


Figure 4 Cross-axis or cross flow turbine design principle [18].

The next common design principle is the oscillating hydrofoil. These devices incorporate a hydrofoil which is mounted to an arm. As water flows past the hydrofoil lift is generated and the arm moves in one direction, as the hydrofoil reaches the limit of its movement in the one direction the orientation of the hydrofoil is changed, causing the lift force of the hydrofoil to move the arm in the opposite direction. This process is repeated causing the arm to oscillate as the flow moves past the device. *Figure 5* shows an example of an oscillating hydrofoil.

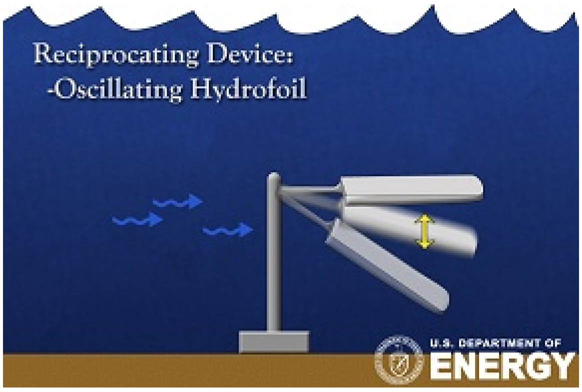


Figure 5 Oscillating hydrofoil design principle [18].

The last common design principle is the enclosed tips (Venturi) type. This design is based on the Venturi effect, which is the reduction in fluid pressure that results when a fluid flows from a larger area pipe to a smaller area pipe. With this type of design, a funnel-like device is used to concentrate the flow past a turbine or the resulting pressure differential can be used to drive an air turbine. One such device is shown as *Figure 6*.

Figure 6 Enclosed tips (Venturi) design principle [19].

If the design did not fit into one of those four categories, it was considered a unique design principle, which was labelled “other designs”.

3.2.3 Method to fix the device

Another way of classifying the different devices is to look at how the devices are held in place. There are four main methods to fix the devices, and the technology providers were asked to identify which methods could be used for their particular technology [17].

The first is the seabed mounted / gravity base. With this method, the device is attached to the bottom directly, or is heavy enough that it is held in place by the static friction force generated by its own weight.

Pile mounted devices consist of a pole that penetrates the ocean floor. Some technologies use piles to allow the device to align with the flow and others use the pile to allow the devices to be raised out of the water for maintenance.

The third classification of fixing applies to devices that are floating. This classification has three subdivisions. Floating devices can be fixed by flexible mooring, which means that the device is tethered to the seabed and has significant freedom of movement. Alternatively, if less freedom of movement is desired, a rigid mooring can be used. The last subdivision for a floating device is the floating structure, which allows for several devices to be mounted to the floating platform.

The last main fixing method is using a hydrofoil attached to the device. As flow passes the hydrofoil, a downward force is induced, resulting in a static friction force that keeps device in place. As the flow speed increases, the downward force increases, meaning that the fixing force, to some degree, self-adjusts to the flow conditions.

3.3 Technology status

Because so few tidal in-stream conversions technologies are to the commercial phase at this point, understanding how far a technology has come in the development process is important to capture in the technology survey. The next set of questions in the RFI were aimed at developing a picture of the current status of the device and determining how long it will take before the technology is to a stage where it could be utilized on a larger scale.

3.3.1 Development status

The U.S. department of energy (DOE) has adopted a set of technology readiness levels (TRLs) in the area of marine and hydrokinetic technology industry. Technology readiness levels were originally used by that National Aeronautics and Space Administration (NASA) and are used to assess how mature evolving technologies are. The technology developers were asked to classify the TRL of their technology according to the following criteria which are directly taken from the DOE website [18]:

TRL 1-3: Discovery / Concept Definition / Early Stag Development, Design and Engineering

- TRL 1-2: These are the lowest levels of technology readiness. Scientific research begins to be translated into applied research and development where basic principles are observed and reported. Technology concept and application are formulated and investigated through analytic studies and in-depth investigations of principal design considerations. This stage is characterized by paper studies, concept exploration, and planning.
- TRL 3: In this stage, active research is initiated, including engineering studies and laboratory studies to physically validate analytical predictions of separate elements of the technology.

The purpose of this stage is to evaluate, insofar as possible, the scientific or technical merit and feasibility of ideas that appear to have commercial potential.

TRL 4: Proof of Concept

- In this stage basic technological components of a sub-scale model are integrated to validate design predictions and system level functionality. The models, or critical subsystems, are tested in a laboratory environment.

This TRL represents early stage proof-of-concept system or component development, testing and concept validation. In this stage, critical technology elements are developed and tested in a laboratory environment. It is envisioned that scale models will be at 1:10 scale or smaller.

TRL 5/6: System Integration, and Technology Laboratory Demonstration

- TRL 5: At this level, basic technological components are fabricated at a scale relevant to full scale and integrated to establish and verify subsystem and system level functionality and preparation for testing in a simulated environment.
- TRL 6: At this level, representative model or prototype system at a scale relevant to full scale, which is beyond that of TRL 5, is tested in a relevant environment. This stage represents a major step up in a technology's demonstrated readiness and risk mitigation and is the stage leading to open water testing.

At this stage device, system, and subsystem level interfacing/integration testing represent a vital stage in technology development, and must be demonstrated. Models should be at a relevant scale (1:1 – 1:5) to reflect the challenges and realities of the full scale (1:1) system. Model testing is to be performed in a test facility capable of producing simulated waves/currents and other operational conditions while monitoring device response and performance. Furthermore, the devices foundation concept shall be incorporated and demonstrated.

TRL 7/8: Open Water System Testing, Demonstration, and Operation

- TRL 7: At this level, the prototype scale components and subsystems are fabricated and integrated to establish and verify subsystem and system level functionality and preparation for testing in an open water operational environment to verify expected operation and fine tune the design prior to deployment in an operational demonstration project.
- TRL 8: At this level, the prototype in its final form (at or near full scale) is to be tested, and qualified in an open water environment under all expected operating conditions to demonstrate readiness for commercial deployment in a demonstration project. Testing should include extreme conditions.

At this stage, the device model scale is expected to be at or near full scale (1:1 – 1:2). Testing may be initially performed in water at a relatively benign location, with the expectation that testing then be performed in a fully exposed, open water environment, where representative operating environments can be experienced. The final foundation/mooring design shall be incorporated into model testing at this stage.

DOE TRL 9: Commercial-Scale Production / Application

- At this stage, the actual, commercial-scale system is proven through successful mission operations, whereby it is fielded and in-use in commercial application.

This stage represents an in-service application of the technology in its final form and under mission condition

3.3.2 Description of testing activities

Prototype testing of these devices is an extremely important part of proving that that they will function in real world conditions. It is therefore important to understand the amount of testing that has been performed on each device. The technology providers were asked to describe all of their prototype testing activities including the scale of the test, test facility or location of the testing, the dates and the hours of operation during the testing. All of those parameters should give a good understanding of how much testing is complete, and how much testing needs to be done before the device can be declared a success or not.

3.3.3 Next development steps

The technology developers were asked to briefly describe their next development steps. This question was intended to give us an understanding what coming tasks the developer has judged to be the most important next phase of development for their particular technology.

3.3.4 Environmental impact studies

Several reports exists where the potential environmental impacts of TISEC devices has been explored. Such studies generally look into installation, operation and decommissioning and how these activities affect the surrounding environment. While the impact is in many cases presumed to be small, there is little long term data from actual installations because the technology is still in such an early development stage [12]. The environmental impacts will often times depend on the specific technology and the location of the installation. With that in mind, one of the questions for the request for information was to describe if the developer had performed any environmental impact studies for their specific technology.

3.3.5 Technical publications

The developers were also asked to list any technical publications that contain data about their technology. At a later stage in the project, where more detailed information about the technology is needed, technical publications could be useful for helping understanding the details of the concept better or for understanding the methods used to generating vital performance data. Having technical publications also shows that the developer has incorporated an academic aspect in their development plan.

3.3.6 Estimated date commercially available

The developers were asked to estimate a date when the technology would be commercially available. The answer to this question will be used to determine if it is feasible that the technology will be ready for large scale utilization within an acceptable timeframe for the Ferry Free E39 project.

3.4 Operational characteristics

The next category of questions was developed to gain information about the operational characteristics of the technologies.

3.4.1 General operational characteristics

The general operational characteristics of the device include information about the dimensions, area of current flow used by the device, weight of super structure and weight of power conversion equipment. When the locations of the crossings are determined, this information could be useful in determining how many TISEC devices would be able to fit in the crossing. This information is also useful for determining some of the additional loads that the bridging structure will need to withstand as a result of adding the TISEC devices.

3.4.2 Installation requirements

Information about the installation requirements of the technologies is critical in determining whether or not the individual devices could be used for the different crossings. The minimum installation depth and maximum installation depth were requested. Additionally, the lowest flow speed in which the device can be utilized (cut in speed) and the maximum allowable flow speed were also requested.

3.4.3 Performance characteristics

The technology developers were asked to identify the rated flow speed and the rated power of their devices. Additionally, information was requested about the estimated power outputs at various current speeds. Because the tidal flows vary drastically throughout the various stages of the tidal cycles, in order to estimate power production over a longer period it is necessary to understand how the devices behave over a broad range of flow speeds.

3.4.4 Economic characteristics

To facilitate cost comparisons of the various devices in the future, information was requested about the costs of the devices. Because it is assumed that the devices will be past the research and development phase by the time they will be utilized for the Ferry Free E39 project, the requested cost was for a production level device. Additionally, information about the design lifetime was requested in order to be able to determine the long term economic feasibility of the devices.

3.5 Relevance to Ferry Free E39

The last type of questions gave the technology developers the chance to explain how their particular devices could specifically be utilized for the Ferry Free E39 project. The developers were asked if and how their device could be combined with a suspension bridge fjord crossing, a floating bridge fjord crossing and a submerged floating tunnel fjord crossing. Other questions asked them to explore the possible advantages and disadvantages of combining their device with such structures. Because the technology developers know the strengths and limitations of their devices best, it was decided that this was an effective way of determining how feasible it is to combine these types of devices with infrastructure, and what the advantages and disadvantages are.

3.6 List of developers

Table A2:1 shows the technology developers with whom contact was attempted. All contact information was found on the developer's homepages. If the "Confirmed contact" column is green, it means that a response to the initial contact was received. This response could have been in the form of an automatically generated email, personal email, or telephone call. If the "Confirmed contact" column is red, it means that no response to the initial contact was received or that the email address that was used led to a failed email notification. If the "Responded to RFI" column is green, this means that the developer responded to the request for information. If this column is red, it means that for whatever reason, no response was received from that particular developer.

4 Tidal energy conversion technology state of the art summary

Table A3:1 shows some basic information about the technologies that responded to the RFI. There were a total of 19 technology developers who responded to the RFI. Several of the developers were unable to reply to the RFI or limited their response due to the fact that the information was going to be distributed beyond our organization. Several companies were unable to respond because of limited time or personnel resources. The complete responses from all of the developers who responded to the RFI are included in *Appendix 3*.

5 Energy from the waves

5.1 How waves are generated

Wave energy is a renewable energy source that indirectly originates from solar energy. Due to the complexities of the Earth's surface and the relative location of sun to the different locations on Earth, the Sun causes the Earth to be heated unevenly. As air gets heated up, it becomes less dense and tends to rise. As the warmer air rises, this leaves room for denser colder air to take its place. As the warmer and colder air shift locations, wind is generated.

As the wind blows across the ocean surface, the friction between the wind and the water surface creates ripples which grow until waves are produced. Waves that are generated from wind have a very high energy concentration. Wind waves are a natural storage of wind energy and can travel thousands of kilometres with little energy losses [3]. A diagram depicting a typical wind wave generation scenario is shown as *Figure 7*.

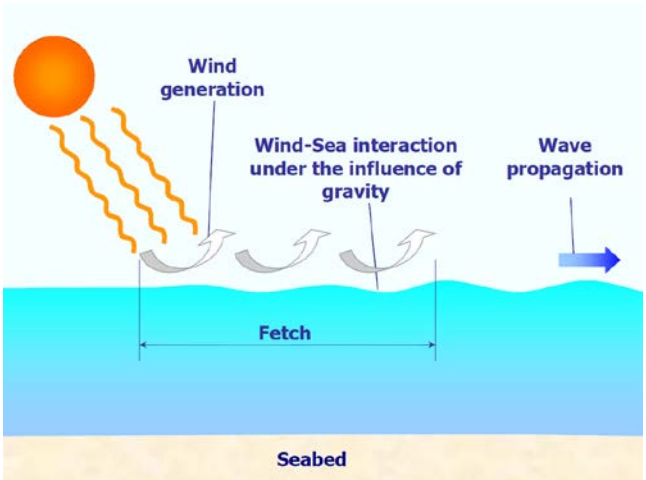


Figure 7 Wind wave generation [3].

5.2 Wave energy conversion

Much like with tidal energy, extracting energy from the waves is not a new idea. The first patent on wave energy conversion was issued as early as 1799 [20].

Much like the tidal current energy conversion devices, the first real interest in large scale wave energy conversion (WEC) devices came as a result of the oil crisis in the 1970s. However much of the funding did not last past the early 1980s and focus shifted away from the WEC development [21].

In 1991, the European Commission included wave energy in their research and development program for renewable energies. Since that time, many new breakthroughs have been made and a wide range of technologies have been developed. The first experimental wave farm was opened in Portugal at the Aguçadoura Wave Park in 2008.

Although there is a broad range of estimates of the global wave energy resources, most agree that wave power is one of the most abundant sources on earth [22]. Siegel et al. have made a powerful comparison between the World Energy Council's estimate of the global annual amount of wave power energy of 17.5 PWh (Peta Watt hours = 10^{12} kWh) with the currently estimated annual worldwide electric energy consumption of 16 PWh.

In one study, it was estimated that around 600 TWh of total wave energy reached the Norwegian coast per year [16]. When one accounts for the efficiency of the energy conversion and the amount of coast that is acceptable to develop for wave energy, the estimated contribution of wave energy to the Norwegian energy portfolio could reach between 12 to 30 TWh per year [16].

6 Wave energy conversion technology request for information

As the WEC technology industry is also in a very early stage of development, it was again decided that the best method for ensuring that the most relevant information was obtained for the technology survey was to send out an RFI to the technology developers.

The RFI process could again be used to establish contact with the developers and to inform the developers, stakeholders and research groups about the Ferry Free E39 workshop/conference.

While the formatting of the RFI that was sent to the WEC device developers was intentionally kept similar to the RFI that was sent to the TISEC device developers, many updates were made in order for the questions to be more relevant to these types of devices. Although several of the questions are different, the RFI for WEC device developers can again be broken up into the same five basic categories: general information, device classification, technology status, operational characteristics, and relevance to the Ferry Free E39 project.

Again, the technology providers were informed that if any of the requested information was currently unavailable that they could simply state that in their reply. A fictional sample reply was again provided in an attempt to give some guidance as to the desired style and format of the responses. The RFI that was sent to the WEC device developers and the sample reply are included as *Appendix 4*.

6.1 General information

The general information questions for the WEC device developers are identical to those for the TISEC device developers described in section 3.1

6.2 Device classification

WEC devices are much like the TISEC devices in that they have a very wide range of solutions currently under consideration. The device classification questions of the WEC RFI are meant to gain an understanding of what makes the particular technologies unique, and at the same time allowing for relevant comparisons to be made between the different devices.

6.2.1 General device classification information

Again, the general device classification questions allow the developer to discuss what makes their concept unique. The developer was asked to explain the basic features and design principle that their technology employs. Additionally, the developer was asked to describe the method in which the energy is converted from the waves into a more usable form of energy. This system is commonly referred to as the power take-off (PTO) system.

6.2.2 Device type

There are six basic design principles that can be used to describe the majority of the WEC devices [17]. In the RFI, the WEC device developers were asked to classify their device according to those principles or to state that it was a unique concept that did not fall into one of those categories. The six basic design principles are shown in *Figure 8* through *Figure 12*.

The first design principle is referred to as an attenuator. An attenuator is a multisegmented floating device that is able to ride over the waves. The working direction is parallel to the wave travel. Movements along the length of the attenuator cause the device to flex where the segments connect and this flexing motion is used to convert the wave energy into useful energy via hydraulic pumps or other converters. As these types of devices ride over the waves and have a relatively smaller area parallel to the waves, they do not need to be designed to withstand the level of loads that some of the other device types experience. *Figure 8* shows the basic attenuator design principle.

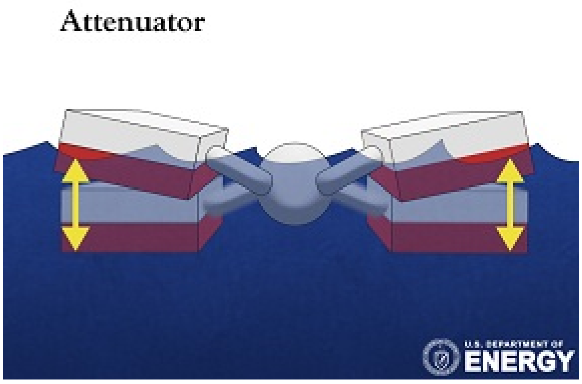


Figure 8 Attenuator design principle [18].

A floating point absorber is a floating structure that is capable of absorbing wave energy from all directions. The overall dimensions of the point absorber are typically relatively small when compared to the wavelength and this type of device can capture energy from a wave that is larger than the dimensions of the device [18]. As a wave reaches the floating point absorber, the float moves relative to other device structures. This relative motion is converted to energy via electromechanical or hydraulic energy converters.

The submerged pressure differential device is similar to the floating point absorber. It is also a point absorber in that the overall dimensions are smaller than the wavelength and that it can capture energy from a wave that is larger than the dimensions of the device. The main difference is that this device does not float on the surface, but rather floats under the surface. Instead of capturing the energy by floating up and down on top of the waves, the submerged pressure differential device captures the energy of the oscillating pressure increase and reduction that results from the waves passing over the device. Again the relative motion between the point absorber and the rest of the structure is used to convert the wave energy into more useful forms of energy. Both the floating point absorber and the submerged pressure differential design principles are shown in *Figure 9*.

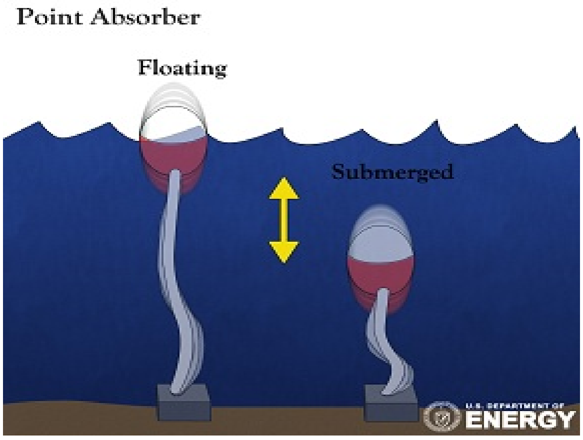


Figure 9 Floating point absorber and submerged pressure differential design principles [18].

Oscillating wave surge converter devices are used at the shoreline or for near-shore applications. These devices consist of an arm, flap, float or membrane that is capable of rotating about a fixed point or axis. As the water particles in the wave surges move back and forth, the arm, flap, float or membrane oscillates about the rotation centre and this relative motion is converted into useful energy. One example of an oscillating wave surge converter is shown in *Figure 10*.

Figure 10 Oscillating wave surge converter design principle [18].

An oscillating water column device consists of a partially submerged structure that encloses a column of air above the waterline and is open to the sea below the waterline. As a wave passes the device, the water column rises and falls, leading to a corresponding pressure increase and decrease in the air column. As the pressure changes in the air column, the air is pushed and pulled through a turbine, which converts the energy in the airflow into rotation of the turbine blades, which is then converted into electricity. These devices can be utilized as floating devices or as shore-based devices. The basic principle of the oscillating water column is shown in *Figure 11*.

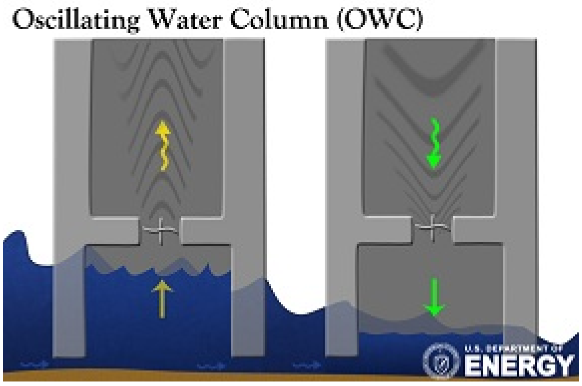


Figure 11   Oscillating water column design principle [18].

An overtopping/terminator device consists of a partially submerged structure that is formed to allow water from waves to travel up a ramp and into a water reservoir that is above the waterline. As gravity causes the water to return to sea-level, it passes through conventional low-head turbines, which are used to generate power. These devices can also be utilized as floating devices or as shore-based devices. A simple schematic of the overtopping design principle is given as *Figure 12.*

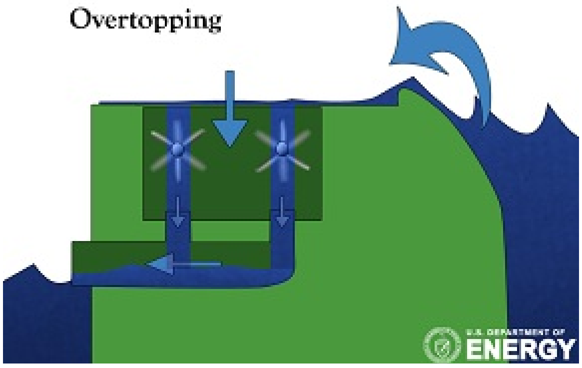


Figure 12   Overtopping design principle [18].

If the design did not fit into one of the six aforementioned categories, the technology was listed as “other designs”.

6.2.3 Device survivability

Because of the extremely hostile environment that WEC devices must be able to endure in storm conditions, one key aspect of classifying the devices is how survivability has been addressed by the developer. The technology developers were asked to give a brief description of the survivability strategy of their device and whether or not the survivability system had been tested.

6.3 Technology status

The questions of the RFI that was sent to the WEC technology providers relating to the technology status were again focused around the development status, description of testing activities, next development steps, environmental impact studies, technical publications and estimated date the technology would be commercially available. For a detailed description of those questions, the reader is referred to section 3.3.

6.4 Operational characteristics

The operational characteristics of the WEC devices are important when considering if it is possible to incorporate the devices into the design of the bridging structures at each of the crossing.

6.4.1 General operational characteristics

The questions about the general operational characteristics of the device are meant to obtain information about the dimensions, weight of super structure and weight of PTO system. Additionally, information was requested about how far apart the devices should be spaced if multiple devices were to be used. When the locations of the crossings are determined, this information could be useful in determining how many WEC devices would be able to fit in the crossing. This information is also useful for determining additional loads that the WEC devices will exert on the bridging structures.

6.4.2 Installation requirements

Information about the installation requirements of the technologies makes it possible to determine which devices could potentially be utilized at the different crossings. The minimum installation depth and maximum installation depth were requested.

6.4.3 Performance characteristics

The WEC device developers were asked to identify the rated power of their technology. Additionally, wave energy absorption performance as a function of significant wave height and peak wave period was requested. In order to accurately calculate the energy absorption of a WEC device, this performance matrix can be compared with the wave resource data for a specific location, which has also been quantified according to significant wave height and peak wave period [23]. Because this performance matrix is so vital to determining accurate estimations of energy absorption, the source of this data is also important. The developers were asked whether this information was generated from numerical simulations or random wave model tests.

6.4.4 Economic characteristics

Because cost comparisons of these devices will be relevant at a later stage of the Ferry Free E39 project, information was again requested about the costs of a production level devices and the design lifetime of the technologies.

6.5 Relevance to Ferry Free E39

The developers were finally asked whether or not it was possible to combine their device with a fjord crossing that implements a suspension bridge, floating bridge or submerged floating tunnel and to explain how their device could possibly be combined with these types of structures. Initial investigations showed that many of the WEC devices were designed specifically for offshore wave environments. Because this stage of the project is intended to survey the entire WEC industry, it was decided that the developers should be encouraged to respond even if they currently did not envision their technology being compatible with a bridging structure in the fjords. With this in mind, it was stated in the RFI that if their device is best suited for offshore applications that the possibility to install the device in other locations such as offshore would be considered.

6.6 List of developers

Table A5:1 shows the WEC technology developers with whom contact was attempted. All contact information was found on the homepages of the specific developers. The same colour coding that was described in section 3.6 is used for *Table A5:1*.

7 Wave energy conversion technology state of the art summary

Some basic information obtained from the WEC device RFI is shown in *Table A6:1*. There were a total of 31 responses to the RFI received (one developer submitted responses for three different technologies). Several of the developers were unable to reply to the RFI or limited their response due to the fact that the information was going to be distributed beyond our organization. Several companies were unable to respond because of limited time or personnel resources. The complete responses from all of the developers who responded to the RFI are included in *Appendix 6*.

8 Crossing locations

Because the potential energy output from wave and tidal energy conversion devices is extremely dependent on the wave and tidal resources at the specific installation location of the device, one of the first steps towards estimating the potential output is to determine where the devices will be installed. For the Ferry Free E39 project, eight fjord crossings need to be considered:

- Kanestraum-Halsa (Halsafjord)
- Vestnes-Molde (Moldefjord)
- Festøy-Solavågen (Storfjord)
- Volda-Folkestad (Voldafjord)
- Anda-Lote (Nordfjord)
- Opedal-Lavik (Sognefjord)
- Sandvikvågen-Halhjem (Bjørnafjord)
- Mortavika-Arsvågen (Boknafjord)

As energy production is just one aspect of the Ferry Free E39 project, it is unlikely that the location of the crossings will be decided solely based on the best location for energy production. With spans of up to 25 km in fjords with depths up 1300 m, the bridging technologies will be impressive engineering feats in of themselves. In all likelihood, because of the challenges that the designers face to simply construct bridges that will function in these locations, some of the crossings may even intentionally be situated in areas where the tides and waves are not most energetic.

When determining a location for the crossings, a host of other factors including location of existing infrastructure, conflicts with business interests and environmental concerns must also be considered. Because the relative importance each of these variables is currently unknown, at this point it was decided, a good first approximation is to assume that the crossings are based on the shortest distance in the area near the current ferry route. By decreasing the length of the crossing, costs can be significantly reduced. Additionally, by choosing the shortest crossings, the wind and tidal current resources are also typically maximized.

Figures of each of the eight crossings are shown below as *Figure A7:1* through *Figure A7:8*. The proposed crossings are shown in red and the current ferry route is shown in blue.

The approximate lengths of the proposed crossing locations are shown in *Table 1*. For Bjørnafjord, the two different proposed crossings are labelled Bjørna a and Bjørna b for the southern crossing and the northern crossing respectively. The crossings are each given a unique crossing number, which is used in some of the tables shown later in the report.

Table 1 Proposed crossing information.

	Halsa	**Molde**	**Stor**	**Volda**	**Nord**	**Sogne**	**Bjørna a**	**Bjørna b**	**Bokna**
Crossing #	1	2	3	4	5	6	7a	7b	8
Length (m)	1829	8034	3400	2014	1700	3810	1600	5732	8416

9 Bridging technologies

Because the designs of the bridges are still undetermined at this point, the all of the different bridging technologies must be considered when making estimates of the energy production potential at the different fjord crossing locations. There are three types of bridging technologies that are currently under consideration for the different crossings: suspension bridges, floating bridges, and submerged floating tunnels.

9.1 Suspension bridge

The suspension bridge is a traditional bridging technology. The bridge typically has towers with suspension cables that run through the towers and are anchored to land. Vertical suspender cables or rods connect the suspension cables to the deck, which is the load-bearing portion of the roadway. A concept for a suspension bridge technology used for the Sognefjord crossing from the Norwegian Public Roads Administrations feasibility study is shown as *Figure 13* [25].

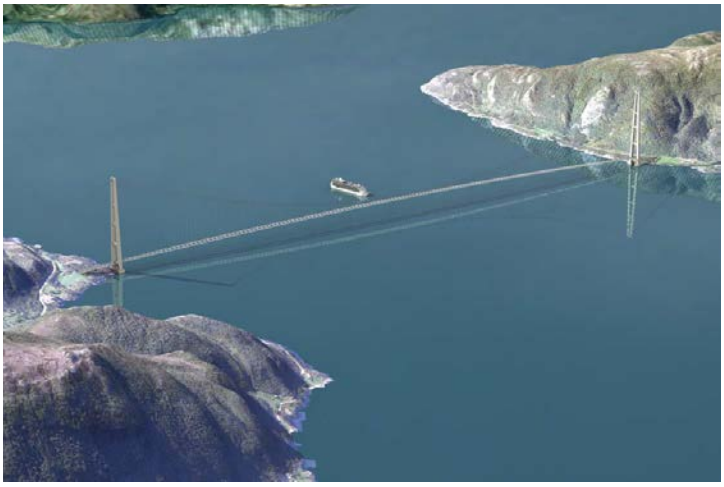


Figure 13 Suspension bridge example [25].

9.2 Floating bridge

A floating bridge, or pontoon bridge, is a bridging technology that incorporates floating pontoons that have enough buoyancy to support the deck, service loads, and any dynamic loads the bridge may experience. An example of a floating bridge concept with an opening for ship passage from the Sognefjord crossing feasibility study is shown as *Figure 14* [25].

9.3 Submerged floating tunnel

The submerged floating tunnel concept is an innovative bridging technology that takes advantage of the inherent buoyancy of tunnels that are under the surface of the water which house the road surface. By calculating the weight of the displaced fluid and matching the weight of the tunnel to that, the tunnel is approximately neutrally buoyant. The tunnel is then either anchored to the seafloor, shore or to pontoons floating on the surface. Images of a submerged floating tunnel concept from above the water surface and below the water surface are shown respectively as *Figure 15* and *Figure 16*.

Figure 14 Floating bridge example [25].

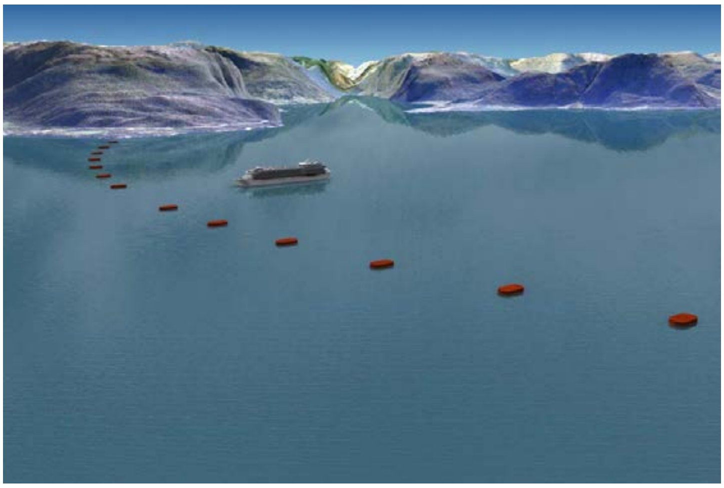


Figure 15 Submerged floating tunnel seen from above the water surface [25].

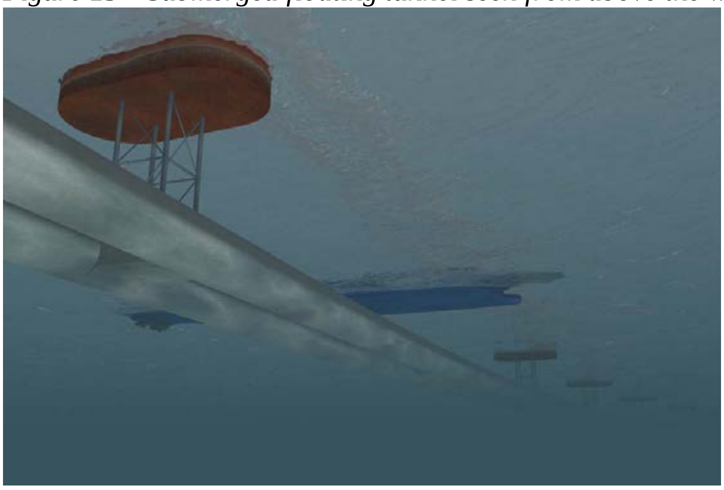


Figure 16 Submerged floating tunnel seen from below the water surface [25].

10 Determining tidal energy potential

The first step in determining if it is feasible to use tidal energy conversion devices in combination with the bridging structures is to quantify the tidal resources at the specific fjord crossings. If the tidal current flow rates in the areas of interest are not significant, the devices will operate at low efficiencies and very little energy will be produced. The next step is to look closer at the specific technologies that convert kinetic tidal energy. The possibility of combining the specific devices with the different bridging technologies is investigated and estimations of the potential number of devices that can be utilized at each of the fjord crossing locations are made. Rough calculations of the annual energy production from the different devices are presented and recommendations are made about what the next steps should be when considering combining tidal energy conversion devices with the fjord crossings.

10.1 Tidal resources

Because the tidal currents vary with time and location, in order to accurately determine the total tidal resources of a particular location the annual distribution of water velocities must be known. Typically data from at least a single year is required to ensure that seasonal differences in the energy flux are accounted for.

It is a well-known fact that there are variations in the flow field near a solid boundary due to boundary layer effects. The no slip condition between fluid and the boundary means that the flow near the edges of the crossings and at the seabed is lower than it is in the middle of the channel. Because knowing the actual flow characteristics across the channel requires a detailed analysis of the flow and the bathymetry of the channel, typically assumptions are made about the variations in the flow field in order to account for variations in the flow speed as a function of depth and cross-channel location.

In order to take into account variations in the speed as a function of depth, the 1/10th power law approximation is commonly used [26]. This 1/10th power law is used to determine the flow velocity throughout the depth of the flow and can be represented as follows:

$$u(z) = u_o \left(\frac{z}{z_o}\right)^{1/10}$$

where *u(z)* is the velocity at depth z, and u_o is the reference velocity at the reference depth z_o. Depth is measured relative to the seabed, where z is equal to 0. Using this approximation, a depth-averaged current velocity distribution can be determined from current velocity data that is typically measured at the surface. The annual distribution of the depth averaged velocities can be broken up into bins and the frequency of the velocities in each bin can be plotted as shown in *Figure 17.*

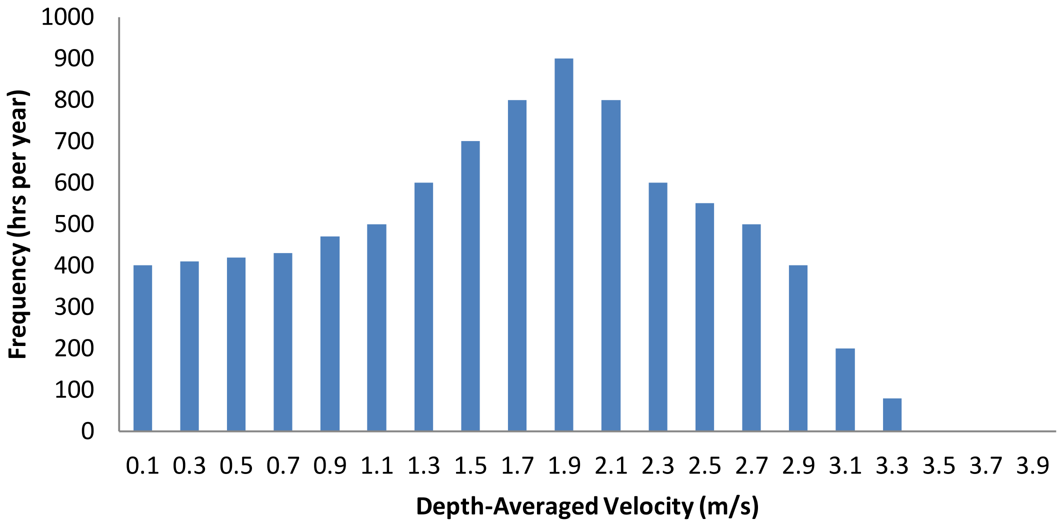


Figure 17 Fictional example of annual depth-averaged velocity distribution.

Once the depth-averaged current velocity is determined, an assumption has to be made about the cross channel variation. For feasibility level studies, a common assumption is that there is no variation in the flow across channel [26]. While this overestimates the available resource, it is often a necessary approximation in the absence of other data.

With these assumptions, the annual total tidal energy resource (E_{annual}) can be expressed by the following equation:

$$E_{annual} = \frac{1}{2}\rho \cdot A \sum_{i=1}^{n} f_i {u_i}^3$$

where ρ is the density of seawater (1025 kg/m^3), A is the cross-sectional area of the channel, f_i is the annual frequency (hours/year) of the current velocity u_i and n is the total number of velocity bins.

Unfortunately, very little current velocity data is currently available in the regions where the fjord crossings are proposed. In a draft report released to the investigators, the authors concluded that there were very little tidal resources in the following fjord locations [27]:

- Kanestraum-Halsa (Halsafjord)
- Festøy-Solavågen (Storfjord)
- Opedal-Lavik (Sognefjord)
- Sandvikvågen-Halhjem (Bjørnafjord)

For the following proposed crossing locations, no detailed information about the tidal current velocities was available at the time the feasibility study was concluded:

- Vestnes-Molde (Moldefjord)
- Volda-Folkestad (Voldafjord)
- Anda-Lote (Nordfjord)

- Mortavika-Arsvågen (Boknafjord)

Because the tidal currents depend so strongly on the bathymetry of the specific location, it is feasible that there are significant tidal resources at the fjord crossing locations where we have no data despite the fact that the other fjord crossing locations did not have very promising tidal resources. However, with no detailed information available, it was not possible to calculate the available tidal resources for the fjord crossing locations. When more tidal resource data is available, the methods described above can be used to determine the tidal resource available for the proposed fjord crossing locations.

10.2 Combining tidal energy conversion devices with bridging technologies

The main goal of this part of the project is to reduce the cost of the renewable energy plant by combining the technologies with bridging structures for the different fjord crossings. The developers were asked in the RFI to discuss potential ways in which their technology could be combined with a suspension bridge, floating bridge, or submerged floating tunnel. The developers were also asked to explain the advantages and disadvantages of combining their devices with the different bridging technologies. The responses to these questions are discussed in this section. Additionally limitations and requirements which can be used to determine the number of devices that can be utilized at each location are investigated.

10.2.1 Concepts

Many of the developers responded positively when asked if their devices could be combined with the different bridging technologies. The full responses of the developers are given in *Appendix 3*. The different concepts for combining the devices with the bridge technologies can be summarized as follows:

- Suspending the TISEC devices from the bridge structure using inverted pylons
- Suspending the TISEC devices from the bridge using a rigid frame
- Attaching the TISEC devices to the bridge piles or foundations
- Mooring the TISEC device directly to the bridge
- Connecting the TISEC devices to floating platforms which are moored to the bridge
- Integrating the TISEC device into the bridge structure itself
- Mounting the devices directly to the submerged floating tunnel (either above or below)

10.2.2 Advantages

The developers were asked to discuss the possible advantages of combining their device with the bridging structures. Many of the concepts are applicable for all three of the different bridging technologies.

The main advantages were focused on the cost savings that can be generated by combining the technologies with the bridging structures. The most common mention of costs savings was related to installation and maintenance. By having the devices integrated into the infrastructure, the required time for vessels and divers is significantly reduced or even eliminated, which can amount to a huge cost savings over the lifetime of the device. Additionally, cost savings could be realized by using the bridge structure as part of the foundation instead of having individual foundations for each device. By mooring devices directly to the bridge structure, mooring line lengths are reduced, which also reduces costs. Lastly, the costs associated with cables are reduced because of the possibility of shorter and more effective cable runs.

The other advantages were focused on increases in performance that can be realized by combining the devices with the bridge structures. With the faster currents closer to the surface, having the bridge as an attachment point means that the device installation depth can be better optimized regardless of the depth of the fjord. Another advantage of combining the devices with the bridging technologies is that the shape of bridge structure itself could be used to increase the flow rate to the devices, leading to higher energy output. It was also mentioned that the blockage effect of multiple turbines could create a small pressure head difference across the devices, further increasing their performance.

10.2.3 Disadvantages

The disadvantages of combining the devices to the bridge structures were also discussed.

One of the major disadvantages of attaching device to any of the bridging technologies is the additional horizontal and torsional loads that will be induced into the structure. As mentioned previously, in several locations, the design of the bridges themselves are a significant challenge. The spans of some of the crossings could reach record lengths for some of the bridging techniques. Adding additional loads to the structure by attaching the TISEC devices makes the challenge even more difficult.

One concept for alleviating this problem is to take advantage of the overcapacity that is built into the bridge design. Because the bridges have to be designed for severe loads that result from storm conditions, there is an inherent overcapacity of the structure under normal operating conditions. One could determine a maximum allowable operating current speed which the TISEC devices could be used for. This current speed could be calculated so that the additional loads resulting from the TISEC devices were a safe level below the bridge’s overcapacity. If the current speed were to exceed the maximum allowable speed, the devices could automatically be converted to standby mode. The loads on the bridge would then be reduced until the current speed dropped below the maximum allowable flow rate. Of course the maximum allowable speed will depend on the overcapacity of the bridge, the number and location of the TISEC devices as well as the operational characteristics of the TISEC devices. As the final bridge designs are unknown at this point, calculations of the maximum allowable current speeds are outside the scope of this project and it is assumed that the additional loads on the bridge construction are not a limiting factor for the calculations of potential energy output.

Another disadvantage discussed was the potential for increased dynamic loads that could result from attaching the devices to the structures. While this could be true in some situations, configurations could be envisioned where the addition of support structures for the devices could actually increase the stiffness or damping of the bridging structures, leading to more desirable dynamic characteristics.

The last disadvantage that was mentioned was that attaching the devices to the bridging structures could be a health and safety risk to passing vessels. As personal safety is of utmost importance, this clearly has to be addressed. There must be well marked areas where safe passage is possible and warnings or restraint systems installed to ensure that risks are minimized for passing vessels. This topic is further explored in the separate risk analysis report [28].

10.2.4 Requirements and limitations

When determining the total potential energy output from the TISEC devices, one important part is determining the number of devices that can be utilized for each of the locations. Several requirements and limitations must be considered.

10.2.4.1 Downstream direction

The first requirement is that the concept for generating energy from the tides should incorporate the bridge construction itself, in order to reduce the cost of the renewable power plant. This requirement inherently places a limitation on the number of devices that can be utilized in the downstream direction. Initial investigations of TISEC device farms have used a rule of thumb for downstream device spacing of 10 times the diameter of the device [26]. This spacing is required in order to avoid negative effects on the performance of the downstream device caused by flow disruptions from the upstream device. The number of rows of devices that will fit in the downstream direction is therefore a function of the total width of the bridging structure and the size of the device itself. One can imagine configurations where long mooring lines are attached to the bridge and used to hold floating platforms in place relatively far upstream and downstream of the bridge, but in order to really take advantage of the bridge structure to reduce the costs of the plant, the practical number of rows in the downstream direction is limited by the width of the bridging structure. While the actual required spacing between rows could be different for some technologies, the required fluid flow calculations or testing goes beyond the scope of the present study. With that in mind, a minimum downstream device spacing of 10 times the diameter for horizontal axis or cross-axis turbines and 10 times the width of the device perpendicular to the flow for other types of devices was used for the present study.

10.2.4.2 Cross-stream direction

Another limitation on the number of devices that can be utilized for each crossing is associated with the number of devices that can be placed in the cross-stream direction. In order to avoid negative performance effects on adjacent TISEC devices, a suggested rule of thumb for horizontal axis turbines is to have a 1/2 diameter gap between devices [26]. The rule of thumb is generalized in the present study so that the minimum device spacing is equal to 1/2 the diameter for horizontal axis or cross-axis turbines or 1/2 the width of the device perpendicular to the flow for other types of devices.

Another requirement to be considered is the fact that there must be a location in the bridging structure that is totally free from TISEC devices so that ships can pass the crossing. Using information from one concept of a floating bridge for the Bjørnafjord as a reference, it was decided that all crossings will incorporate a 200 m wide passage for ships which will be free of TISEC devices [29].

When determining the number of devices that fit across the channel, we have taken into account the fact that the flow is lower near the edges and implemented a zone of 100 m from either edge of the crossing where no TISEC devices will be placed.

Additionally, there is a minimum depth in which most TISEC devices can be used. Once the bathymetry of the actual crossing location is known, the number of devices in the cross-stream direction can be reduced if there are areas of the crossing where the minimum depth requirements were not fulfilled. Information about the depth requirements of the specific devices are given in the responses to the RFI. Where no information about the minimum depth requirement is given in the response to the RFI, the minimum allowable depth can be set to equal 1.5 times the height of the device, which is an assumption that has been used in other similar studies [15].

10.2.4.3 Bridge type specific limitations

Upon review of the proposed concepts for combining the renewable energy power plants with the bridge designs, it was noted that there were very few bridge type specific limitations on the number of devices that could be utilized. Though the geometries of the bridge structures vary greatly, with the aid of relatively simple additional structures, the number of devices that could be utilized for the three bridge types is very similar.

All three bridge types could have the same usable width in the downstream direction by adding trusses or wider floating platforms with mooring lines attached to the bridge deck. While these additional structures will naturally increase the cost of the construction, when compared to a TISEC device farm not utilizing infrastructure, the cost of the plant is still significantly reduced and can therefore be considered a viable option at this point.

While there are many possible configurations, some basic concepts that show how the usable width of the different bridges could be equal are shown in *Figure 18* through *Figure 23*. Views are given from both under the water surface and from the side in order to show the details of the basic concepts.

Figure 18 Concept for using truss structures and pontoons to allow for additional rows of TISEC devices in the downstream direction for a suspension bridge (seen from below).

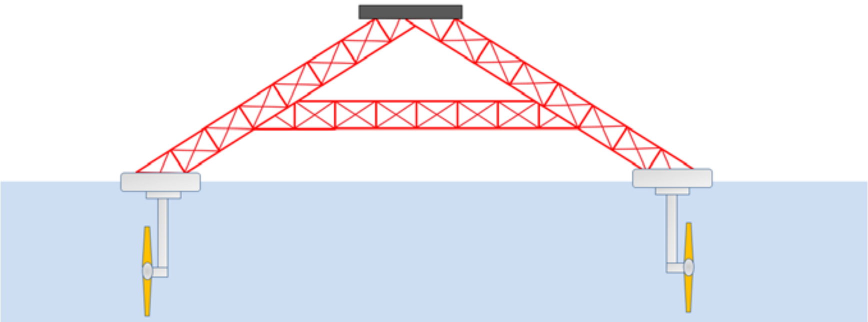


Figure 19 Concept for using truss structures and pontoons to allow for additional rows of TISEC devices in the downstream direction for a suspension bridge (seen from the side).

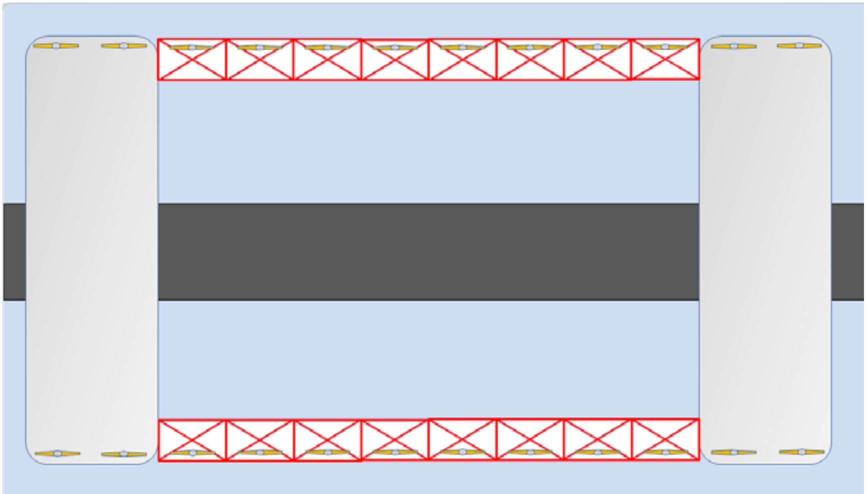


Figure 20 Concept for using truss structures to allow for additional rows of TISEC devices in the downstream direction for a floating bridge (seen from below).

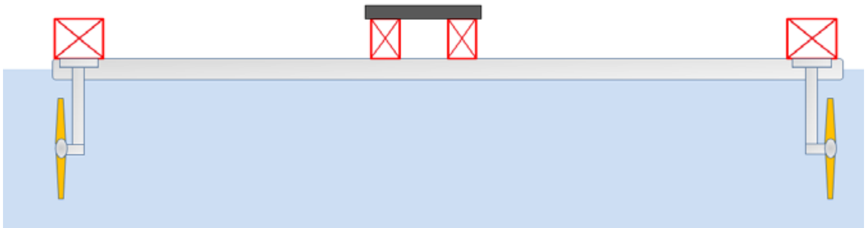


Figure 21 Concept for using truss structures to allow for additional rows of TISEC devices in the downstream direction for a floating bridge (seen from the side).

Figure 22 Concept for using truss structures and pontoons to allow for additional rows of TISEC devices in the downstream direction for a submerged floating tunnel (seen from below).

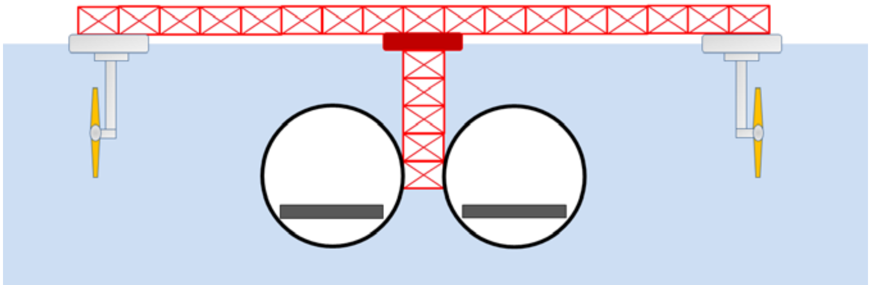


Figure 23 Concept for using truss structures and pontoons to allow for additional rows of TISEC devices in the downstream direction for a submerged floating (seen from the side).

The number of rows of devices in the downstream direction (N_{down}) that can be utilized regardless of bridging technology type is expressed by the following equation

$$N_{down} = 1 + \frac{W_{bridge}}{W_{dev} \cdot 10} - 0.5$$

where W_{bridge} is the width of the bridging structure and W_{dev} is the diameter for horizontal axis or cross-axis turbines and the width of the device perpendicular to the flow for other types of devices.

The result of the equation for N_{down} should be rounded to the nearest whole number. A W_{bridge} of 70 m was chosen for all bridging structures. This value corresponds to the width of the pontoon used in the floating bridge concept for the Bjørnafjord crossing [29]. Although this value was somewhat arbitrarily chosen, it was decided that 70 m gives a good estimate of a reasonable width for such a structure. Using this value, some of the smaller technologies will be able to utilize several rows of devices in the downstream direction with the help of the additional structures.

In the cross-stream direction, additional structures could again be utilized to ensure that the maximum number of devices that can be utilized is relatively unaffected by the choice of bridge type.

For the submerged floating tunnel design, there are some additional limitations that affect the number of devices that can be utilized in the cross-stream direction. These potential limitations are strongly dependent on the details of the bridge design and the bathymetry of the crossing and are therefore hard to quantify at this point in the project. For the submerged floating tunnel design, most of the TISEC devices could be incorporated into the structure either above or below the tunnel. If the devices are to be located above the tunnel, the tunnel would have to be far enough under the surface of the water to ensure that the minimum installation depth was observed. If however the floating tunnel is designed to be located closer to the surface, then the devices will need to be positioned under the tunnel. If the devices are under the tunnel, then the distance between the bottom of the tunnel and the seabed must meet minimum installation depth, meaning that the depth of the crossing will in some cases be more limiting for the submerged floating tunnel design.

The submerged floating tunnel design has additional structures that could also limit the number of TISEC devices that could be installed in the cross-stream direction. In deeper water, the tunnels are typically anchored to pontoons floating on the surface of the water. If the TISEC devices are to be located above the tunnel, the structures attaching the pontoons to the tunnel will limit the space available for the devices. A sketch of the basic concept for a submerged floating tunnel with the TISEC devices located above the tunnel is shown as *Figure 24.* In the figure, one can see that the number of devices is limited due to the pontoon attachment structures.

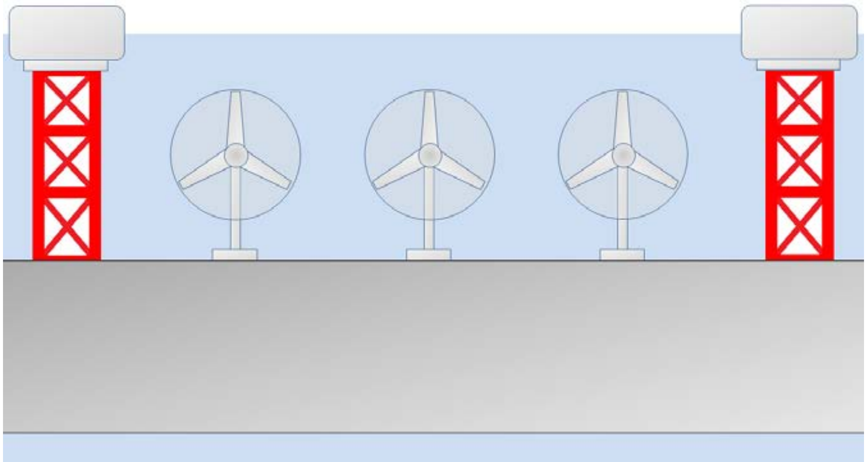


Figure 24 Sketch showing how the number of TISEC devices in the cross-stream direction can be limited by additional structures for a submerged floating tunnel.

For shallower crossings, the tunnels may be anchored to the bottom of the fjord using mooring lines. If the TISEC devices are positioned below the tunnel, these mooring lines could limit the number of devices that can be utilized. Because there are so many unknowns about the final designs of the bridges at this point, a constant reduction factor was assumed for all crossing locations so that the number of TISEC devices that could be utilized in the cross-stream direction is 15% less for a submerged floating tunnel design when compared to the suspension bridge or floating bridge designs.

Sketches of basic concepts for using truss structures to increase the potential number of TISEC devices in the cross-stream direction for the suspension bridge and floating bridge are shown as *Figure 25* and *Figure 26*. From these figures, one can see that many limitations on the number of devices in the cross-stream direction can be eliminated with the use of some additional structures.

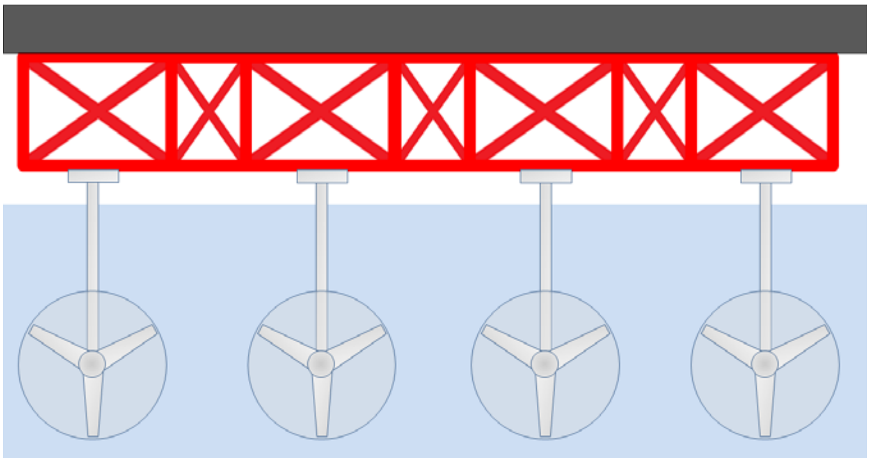


Figure 25 Concept for using truss structures to increase the number of TISEC devices that can be utilized for a suspension bridge.

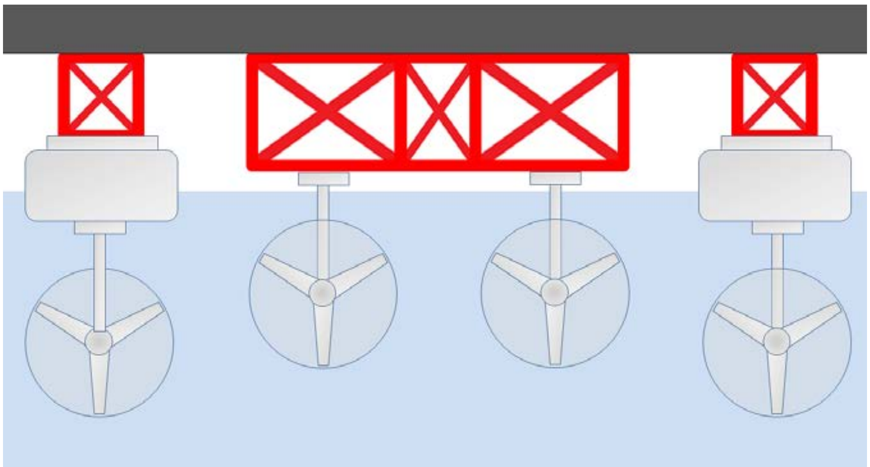


Figure 26 Concept for using truss structures to increase the number of TISEC devices that can be utilized for a floating bridge.

The maximum number of devices in the cross-stream direction (N_{cross}) can be expressed by the following equation

$$N_{cross} = \left[\left(\frac{L_{tot} - L_{depth} - L_{ship} - 2 \cdot L_{edge} - W_{dev}}{L_{dev} + W_{dev}/2}\right) \cdot (1 - R)\right] - 0.5$$

where L_{tot} is the total length of the crossing, L_{depth} is the total length of all of the sections in the crossing where the minimum depth requirement is not met, L_{ship} is the length of the shipping passage (200m), L_{edge} is the distance from the edge of the crossing to the location where devices are first utilized due to reduced flow near the boundaries (100 m), L_{dev} is the length of the device in the cross-stream direction (this value can be different than W_{dev} for cross-axis devices) and R is a reduction factor equal to 0.0 for suspension bridge and floating bridge designs and 0.15 for the submerged floating tunnel design. The result of the equation for N_{cross} should be rounded to the nearest whole number

The total maximum number of devices that can be utilized for each crossing for each bridge type (N_{tot}) can be calculated by simply multiplying N_{down} by N_{cross}.

10.2.4.4 Energy extraction

Another limitation on the number of devices that can be utilized that needs to be considered is the actual amount of energy that can safely be extracted from the flow without creating a negative ecological impact or reducing the current speed. This value is often referred to as the extractable resource and is calculated by multiplying the total resource for a given location by the significant impact factor (SIF). The SIF therefore represents the percentage of the total resource that can be safely extracted [14]. Typical values for SIF are 10% to 20%.

10.3 Tidal energy conversion device output

With no available data for the fjord crossings where current velocities are in the usable range, it was not possible to perform detailed potential energy output calculations at this phase of the project. However, a method for accurate calculations is presented which can be used when the appropriate data is available.

Additionally a greatly simplified method is presented, which is used to give a rough idea of potential annual energy outputs for the different technologies at the different fjord locations if it is found that the fjord crossings have significant tidal resources.

10.3.1 Detailed method for device output calculations

An accurate method to determine the potential energy output of a TISEC device requires that the annual distribution of velocities at the height of the device is known. The same $1/10^{th}$ power law that was described in section 10.1 can be used to convert data that was taken at the surface to velocity information at the height of the device. This data is often simplified to a single location at the centre of the device, which is referred to as a hub-height approximation [26]. The annual distribution of the hub-height velocities can be broken up into bins and the number of hours that the flow exhibits each velocity per year can be plotted. The result is a figure that looks very similar to *Figure 17*.

The device developers were asked to share a curve of electric power output as a function of current speed. This includes information such as the cut in speed, electric output up to the cut out speed, cut out speed and the maximum flow speed. The cut in speed is the minimum flow velocity where the device can generate power. The cut out speed is the speed at which the power output levels out. For flows above the cut out speed, the power output will remain constant until the flow reaches the maximum flow speed. When the maximum flow speed is reached, the devices will go into survival mode and not generate power. The advantage of obtaining this information from the developer is that all of the efficiencies of the device, including the drive train, generator and power conditioning are already taken into account when using this information. By simply taking the number of hours per year at a given flow speed from the annual hub-height velocity distribution and determining the electric power output at that flow, the energy (in watt hours per year) for each velocity bin can be determined. By adding the resultant energy output for all of the bins, the annual energy production from each device is determined (assuming that the device is operated year round).

Several of the device developers were unable to share their electric power output as a function of current speed curve. Some of the developers are at an early enough stage where this information is unknown, while other developers consider this information proprietary, and are not able to share it with the general public. At a later stage of the project, when more detailed energy estimates are required for the individual technologies, it may be necessary to sign non-disclosure agreements with the developers in order to gain access to proprietary information.

The next step is to determine the number of devices that can be utilized for the particular fjord crossing locations. This can be done using the methods described in section 10.2.4. As we have assumed that the cross-channel variations in the flow is to be ignored at this point, the maximum annual energy output for the fjord crossing can be determined by multiplying the number of devices by the annual energy production from each device. This maximum annual energy output assumes that the devices are operated year round and with no losses due to transmission effects.

With the maximum annual energy output for the fjord crossing determined, the next step is to determine the extracted annual resource and compare that to the annual extractable resource limit. The annual extracted energy can be calculated by dividing the maximum annual energy output by the efficiency of the power take-off system. The power take-off system efficiency includes efficiency from the drivetrain, generator and the power conditioning. A suggested power take-off system efficiency is 90% [26]. In cases where the extracted resource exceeds the extractable resource limit for the fjord crossing using an SIF of 10-20%, the number of devices should be reduced until the extractable resource limit is not exceeded.

Down time for maintenance and additional losses due to transmission effects should also be considered when trying to determine realistic annual energy production. One study suggests that availability for these devices should be 95% and the efficiency due to transmission effects should be around 98% [26]. By multiplying the maximum annual energy output by 0.98 and 0.95 an accurate estimate of the annual energy production for the specific crossing location is determined.

10.3.2 Simplified method for device output calculations

As there is currently no flow velocity data available for the four fjord crossings which could potentially utilize TISEC devices, a much simpler approach was used to estimate the potential annual energy production for these devices.

A common measure of system performance in the power production industry is the capacity factor. The capacity factor is the ratio of the actual output of the power plant over a period of time divided by its potential output if it had operated at its full rated capacity over the entire period. In the wind power industry, capacity factors are between 25-30% [15]. It has been suggested that in order for TISEC devices to be competitive with the wind power industry, these devices will have to reach capacity factors of up to 40% [15]. While combining these technologies with infrastructure will reduce the cost of the power plant, thereby reducing the required capacity factor, because the other technologies considered in this feasibility study will also be utilizing the infrastructure to reduce costs, it was decided that 40% is a good estimate of the required capacity factor for the TISEC devices.

As a simple approach to determining an approximate annual energy production where the resources are currently unknown, it was decided that the annual energy production for the remaining fjord crossings would be calculated utilizing the assumed capacity factor of 40%. Using the methods described in section 10.2.4, the number of devices was determined for each of the four fjord crossings and for each of the three fjord crossing technologies. The total annual energy production was then determined using the following equation:

$$E_{TISEC\ annual} = N_{tot} \cdot P_{rated} \cdot CP \cdot 24\frac{hr}{day} \cdot 365\frac{day}{year}$$

where P_{rated} is the rated capacity of the device and CP is the capacity factor.

This estimate does not give any information about whether or not the power plant is in fact viable at the different locations. This estimate simply shows that, if future studies show that the tidal resources for the given fjord crossing is significant enough for a TISEC device plant to be viable, the approximate annual energy production should be on this order of magnitude. This calculation also gives a good idea of the relative amount of energy that the individual technologies might be able to produce.

10.3.3 Calculated device output

Using the fjord crossing lengths shown in *Table 1* for the Moldefjord, Voldafjord, Nordfjord and Boknafjord, the number of devices that can be utilized for each crossing was calculated. The results are shown in *Table A8:1*, where $N_{tot\_sus/float}$ is the total number of devices that can be utilized for a suspension bridge or a floating bridge and N_{tot_SFT} is the total number of devices that can be utilized for a submerged floating tunnel. The reader is referred to *Appendix 8* for the full details of the calculations. The values shown in the table do not take into account fjord specific depth limitations (L_d=0). Where the technology developer did not supply device dimensions, it was not possible to calculate the number of devices that could be utilized.

Using the rated power for each device and the number of devices that can be utilized, the estimated annual energy production was determined for the different technologies, fjord crossing locations and bridging technologies using the assumed capacity factor of 40%. The results are shown in *Table A9:1*, where $E_{sus/float}$ is the annual energy production for a suspension bridge or floating bridge in GWh/yr and E_{SFT} is the annual energy production for a submerged floating tunnel in GWh/yr. At the bottom of the table, the minimum, maximum and average estimated annual energy production for the different technologies is shown. Where the technology developer did not supply device dimensions or the rated power of the device, no calculation of the annual energy production was performed.

One can see from the table that there is a large range of estimated annual energy production from the different technologies. This is in large part due to the variation in the different technology types, sizes of the devices and the flow speed in which the devices are rated. Because of the number of unknowns about the tidal resources, a rough approximation of the annual energy production can be determined by using the average of the different estimates. Using this method, we obtain approximate annual energy productions in (GWh/yr) from suspension bridges or floating bridges of 2875, 603, 486 and 3019 for the Moldefjord, Voldafjord, Nordfjord and Boknafjord respectively. For the submerged floating tunnels, we obtain approximate annual energy productions of 2444, 512, 412 and 2566 for the Moldefjord, Voldafjord, Nordfjord and Boknafjord respectively. If it is assumed that all four of the fjord crossing locations have significant tidal resources the calculations show that the total annual energy production from the TISEC devices is between 5.9 and 7.0 TWh/yr (depending on the bridge designs).

When the calculated values are compared to previous estimations of the annual economical resource in Norway, we see that there is a large discrepancy. The two previously mentioned studies estimated that the maximum total economical resource was around 1TWh/yr for the entire country [15] [16]. Additionally, they had considered that the majority of the tidal resources were further north than the fjord crossings that are being considered for the Ferry Free E39 project.

With the presented calculations grossly overestimating the energy production when compared to previous studies, it can be concluded that at least one of the assumptions made in the calculations is non-conservative. The first potentially erroneous assumption is the fact that the number of devices could be maximized without exceeding reasonable significant impact factors. With no data available for determining the total resources, it was not possible to determine what the significant impact factors of the proposed configurations are. If too many devices are utilized, too much of the energy can be extracted, leading to negative environmental consequences. Another potentially incorrect assumption is that averaging the calculated annual energy production from the different devices would produce a good estimation. With such a large variation in the rated power and rated flow speed of the different technologies and with such a large range of technology readiness levels, it could be that taking the average value of all of the devices leads to non-conservative results. The last potentially non-conservative assumption is the fact that the resources are significant enough to reach a capacity factor of 40%. Again with no tidal resource data for the fjords of interest available it is not possible to know what accurate capacity factors of the different devices are.

10.4 Tidal energy recommendations

The lack of tidal current velocity data makes it impossible to know what the actual potential energy output is from combining TISEC devices with the fjord bridging technologies. Because the different technologies are optimized for different flow conditions, it is not possible to know which technologies would actually provide the most energy for the different crossing locations based on the results shown in the previous section.

It is therefore recommended that the next stage of the study concentrates on obtaining more tidal resource data for the following fjord crossing locations:

- Vestnes-Molde (Moldefjord)
- Volda-Folkestad (Voldafjord)
- Anda-Lote (Nordfjord)
- Mortavika-Arsvågen (Boknafjord)

Initially the resource data could be obtained from models to see if current levels are significant enough to be considered further. The optimum current speed for most technologies is between 1.5-3.5 m/s [13]. If the models show that there is a significant number of hours with current speeds close to this range, then experimental data should be gathered to verify the predictions from the models. This experimental data should be gathered over a significant period of time in order to verify that the models are accurate enough to account for seasonal variations in the flow.

Once detailed information about the annual distribution of current velocities is available, the detailed method for device output calculations described in section 10.3.1 can be used to determine realistic estimates of energy production from the different technologies. For some of the technology developers, it may be necessary to sign non-disclosure agreements in order to gain access to proprietary information about the performance of the TISEC devices. It is recommended that these agreements are signed in order to ensure that all of the options are considered.

Once estimates of energy production are generated for all devices under consideration, comparisons between costs and energy output can be made. These comparisons will give a better basis for making recommendations about whether or not the TISEC device power plant is viable and, if it is viable, which technology or combination of technologies should be utilized for the different fjord crossing locations.

11 Determining wave energy potential

The possibility of combining wave energy conversion devices with bridging technologies at the different fjord crossings is explored in the following section. When determining whether or not it is feasible to use such devices, the wave resources for the specific fjord crossings must be determined. If the wave resources are not sufficient, the devices will produce very little energy. The next step is to look closer at the specific technologies that convert the wave energy into more useful forms of energy. The possibility of combining the specific devices with the different bridging technologies is explored. Estimations of the potential number of devices that can be utilized at each of the fjord crossing locations are also made. Rough calculations of the annual energy production from the different devices are presented and recommendations about what the next steps should be are made.

11.1 Wave resources

Much like tidal currents, waves vary with time and location. Wave energy scatter diagrams typically contain information about annual distribution of the significant wave height (H_s in m), and the peak wave period (T_p in sec). Data from at least a single year is required to ensure that seasonal differences in the energy flux are accounted for. The annual distribution of the significant wave height and peak wave period is usually displayed as a matrix similar to the one shown in *Table 2.*

Table 2 Fictional example of annual wave data where values have units of hours/year.

H_s (m) \ T_p (s)	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
3	0.7	20.1	50.3	99.6	44.9	33.8	39.6	44.1	21.3
2.5	39.9	124.4	243.7	271.9	89.4	83.3	103.0	100.0	48.7
2	298.9	347.5	589.7	549.8	174.9	210.3	270.0	239.6	103.4
1.5	393.1	365.1	623.9	523.9	215.2	282.9	329.3	309.2	155.5

where the values in the matrix are the number of hours per year that the waves exhibit the specific H_s and T_p.

Once the annual distribution of the sea state is known, the incident wave power density for each bin must be determined. The equation

$$J = 0.42 \cdot {H_s}^2 \cdot T_p$$

can be used to calculate the incident wave power density in kW per meter width for each bin assuming that the seastate is well represented by a two-parameter Betschneider spectrum [23]. If the relative amounts of energy in sea and swell components or the shape of the wave spectrum is different than that of the two-parameter Beschneider spectrum, the 0.42 multiplier can vary between 0.3 to 0.5 [23]. The incident wave power density for each bin is multiplied by the number of hours per year in the annual distribution. The sum of these values is the annual incident wave energy density in kWh/m-yr. To determine the annual average incident wave power density at the location (in kW/m), annual incident wave energy density can be divided by the number of hours in the year.

Once the annual incident wave energy density is known, an assumption has to be made about the cross channel variation. For feasibility level studies, it can be assumed that there is no variation in the wave resources across the channel. While this overestimates the available resource, it is often a necessary approximation in the absence of other data.

With this assumption, the annual wave resource (in kWh/year) can be calculated by multiplying the annual incident wave energy density by the width of the channel. Unfortunately, very little wave resource data is currently available in the regions where the fjord crossings are proposed. An investigation into the reasons for this lack of data revealed that modelling of waves in the fjord is a difficult task and experts in the field claim that it is a very time consuming and expensive process. This is partially due to the fact that the swells usually must be accounted for in addition to wind waves and that the geography of the specific site is very important. Additionally there is less satellite data near shore, and not very many in situ buoys, which makes validation of models very difficult.

With no reliable data available, it was not possible to calculate the available wave resources at the fjord crossing locations at this time. When more wave resource data is available, the method described above can be used to determine the wave available for the proposed fjord crossing locations.

11.2 Combining wave conversion devices with bridging technologies

The developers were asked in the RFI to discuss whether or not their technology could be combined with a suspension bridge, floating bridge, or submerged floating tunnel. The responses to these questions are discussed in this section. Limitations and requirements which can be used to determine the number of devices that can be utilized at each location are investigated.

11.2.1 Concepts

While some of the developers did not see a possibility to combine their devices with the bridging structure, several of the developers did respond positively when asked if their devices could be combined with the different bridging technologies. The full responses of the developers are given in *Appendix 6*. The basic concepts for combining the WEC devices with the different bridging technologies are described below:

- Integrating the WEC device into the bridging structure
- Integrating just the power take-off of the device into the bridging structure
- Mooring the WEC device directly to the bridging structure
- Integrating the WEC device into a floating platform, which is then moored to the bridging structure
- Using the WEC as a breakwater that is installed adjacent to the bridging structure

- Replacing a typical mooring line with a lever arm that can be directly attached to the bridging structure

11.2.2 Advantages
Many of the advantages of combining the WEC devices with the bridging structures are similar to those discussed for the TISEC devices in section 10.2.2. Costs savings related to installation and maintenance are again a great advantage of combining the devices with the bridging structures. By using the bridging structures as attachment points for the mooring lines, or as part of the device structure, savings on materials can be realized. The lengths of cable or pipe runs can also be reduced as a result of using the bridging structure as part of the installation which will also reduce costs.

Some of the WEC devices can be used as breakwaters, which could help reduce the loads from waves on the bridging structure themselves.

11.2.3 Disadvantages
One disadvantage of combining the WEC devices with the bridge structures is the fact that location of the installation is in an area where the wave resources are reduced when compared to offshore installations. The depths of the water in the fjords could also pose some limitations on the size of the devices. Several device manufacturers are however able to optimize the parameters of their devices for different locations and wave climates, meaning that the performance of the devices will not necessarily be negatively affected as a result of being located in the fjords.

As discussed in section 10.2.2 for the TISEC devices, one disadvantage with combining the devices with the bridging structures is the additional loads that are induced into the structure. The same concept of using the overcapacity of the bridge during normal operating conditions could again be employed for the WEC devices so that this problem is alleviated.

It can also be envisioned that attaching the WEC devices to the bridging structures will introduce the possibility of a health and safety hazard to passing vessels. The reader is again referred to the risk analysis report for more information about how this problem can be alleviated [28].

11.2.4 Requirements and limitations
To determine the total potential energy output from the WEC devices, the number of devices that can be utilized for each of the crossing locations must be determined. As was the case for the TISEC devices, several requirements and limitations must be considered.

11.2.4.1 Downstream direction
The number of devices must be limited in the downstream direction in order to fulfil the requirement that devices must be combined with the bridging structure. The device developers were asked to provide a centreline device spacing for multiple devices. For most device types, the provided centreline spacing was used as the spacing in both the downstream direction and the cross-stream direction. However, for devices which are much longer in the downstream direction, the number of devices in the downstream direction was limited based on the device's length.

Unfortunately the design of many devices is strongly dependent on the wave climate where the device will be installed. Several of the technology developers failed to provide information about the device spacing requirements due to the lack of available wave resource data. For technology developers that did not supply a device spacing requirement, it is currently not possible to determine the number of devices that could be utilized for the different fjord crossings.

11.2.4.2 Cross-stream direction

In order to determine the number of devices that can be utilized in the cross stream direction, the developer provided centreline spacing was used for all devices. Again a 200 m wide passage was left free of devices in order to allow for the passage of ships [29], and a 100 m distance from each shoreline was left free from devices due to the potential for reduced resources close to the shore.

Additionally, there is a minimum depth in which most WEC devices can be used which should be addressed once the bathymetry of the actual crossing locations is known. The depth requirements of the specific devices are discussed in the responses to the RFI.

11.2.4.3 Bridge type specific limitations

It was again noted that the proposed concepts for combining the WEC devices with the bridging structures had very few bridge type specific limitations on the number of devices that could be utilized. Though the geometry of the bridge structures vary greatly, by adding some relatively simple additional structures like the ones that were discussed in section 10.2.4.3, the number of devices that could be utilized for the three bridge types is very similar.

The number of rows of devices in the downstream direction (N_{down}) that can be utilized regardless of bridging technology type is expressed by the following equation

$$N_{down} = 1 + \frac{W_{bridge}}{W_{space}} - 0.5$$

where W_{bridge} is the width of the bridging structure and W_{space} is the developer provided centreline device spacing.

The result of the equation for N_{down} should be rounded to the nearest whole number. A W_{bridge} of 70 m was again chosen for all bridging structures. Due to the proposed lengths of the devices, the number of devices that can be utilized in the downstream was forced to equal one for the following devices:

- MotorWave group (90-300 m long)
- Sea Power Ltd (140 m long)
- Vigor Wave Energy AB (200 m long)
- Waveenergyfyn (80 m long)
- WavePiston ApS (300 m long)

In the cross-stream direction, additional structures could again be utilized to ensure that the choice of bridge type leads to a minimal effect on the number of devices that can be utilized. The concepts discussed in section 10.2.4.3 are also valid for the WEC devices. As a rough approximation, the same 15% reduction was used when determining the number of WEC device that could be used with the submerged floating tunnel bridge design. The maximum number of devices in the cross-stream direction (N_{cross}) can thus be calculated using the following equation

$$N_{cross} = \left[\left(\frac{L_{tot} - L_{depth} - L_{ship} - 2 \cdot L_{edge} - W_{space}}{W_{space}}\right) \cdot (1 - R)\right] - 0.5$$

The result of the equation for N_{cross} should be rounded to the nearest whole number. The total maximum number of WEC devices that can be utilized for each crossing for each bridge type (N_{tot}) can be calculated by multiplying N_{down} by N_{cross}.

11.3 Wave energy conversion device output

With no wave data currently available for the fjord crossing locations, it was not possible to perform detailed potential energy output calculations at this phase of the project. A method for accurate calculations is again presented which can be used when the appropriate data becomes available.

The simplified method discussed in section 10.3.2 can be applied to the WEC devices in order to get a rough idea of the potential annual energy outputs for the different technologies at the different fjord locations if the wave data collection shows that the fjord crossings have significant wave resources.

11.3.1 Detailed method for device output calculations

In order to accurately determine the potential output of the WEC device, the approximate annual distribution of the significant wave height, and the peak wave period must be known for the specific location of interest.
The device developers were asked to provide a matrix showing the wave power absorption performance (in kW before losses in conversion to electric power) as a function of significant wave height and peak wave period. By multiplying the matrix of the annual distribution of the resources by the matrix of the wave power absorption performance, the total annual absorbed energy (in GWh/yr) can be calculated by summing all of the bins.

The individual device maximum annual energy output can then be calculated by multiplying the total annual absorbed energy by the efficiency of the power take-off system. The power take-off system efficiency includes efficiency from the drivetrain, generator and the power conditioning. The efficiency of the power take-off system is highly dependent on the actual design, and should be based on manufacturer supplied data.

The next step is to determine the number of devices that can be utilized for the particular fjord crossing locations. The methods described in section 11.2.4 can be used to determine the number of devices that can be used for each fjord crossing and each bridge type. By assuming that the cross-channel variations in the waves is to be ignored at this point, the maximum annual energy output for the fjord crossing can be determined by multiplying the number of devices by the annual energy production from each device.

The down time for maintenance and additional losses due to transmission effects must be included when determining a realistic annual energy production estimate. Using the same assumptions made for the TISEC devices, the annual energy production for the specific crossing location can be determined by multiplying the maximum annual energy output for the fjord crossing by 0.98 (for transmission effects) and 0.95 (for availability).

11.3.2 Simplified method for device output calculations

With no wave resource data for the crossings, the simplified approach described in section 10.3.2 was used for the WEC devices. This method again does not give any information about whether or not the power plant is in fact viable at the different locations, but it simply gives an approximate annual production that could be expected if the future data collection reveals that the wave energy resources are significant at the various fjord crossing locations. It also gives a good idea about the amount of energy that the different technologies might be able to produce relative to one another.

A 40% capacity factor was assumed for the WEC device calculations. For developers where it was not envisioned that their device could be combined with a bridging structure, no calculations were performed. The following manufacturers did not see the possibility of combining their devices with any of the bridging technologies in their response to the RFI:

- AW-Energy Oy
- Resolute Marine Energy, Inc.
- Shamil Ayntrazi
- Waveberg Development

It is also noted that some developers responded more generally about their design due to the lack of available wave data. As many devices can be optimized to suit the wave climate, there was some uncertainty in the device size, spacing, and rated power for some of the devices. Where this was the case, best judgements were made based on the available data from the RFI responses. As the estimates calculated at this point in the project are very rough, this approach was deemed acceptable.

11.3.3 Calculated device output

Using the fjord crossing lengths shown in *Table 1*, the number of devices that can be utilized for each crossing was calculated. The total number of devices that can be utilized for the suspension bridge or floating bridge ($N_{tot\_sus/float}$) for the different crossings and technologies are shown in *Table A10:1*, where the different fjord crossings are represented by the crossing number shown in *Table 1*. The total number of devices that can be utilized for the submerged floating tunnel design (N_{tot_SFT}) was also calculated for the different fjord crossing locations and the results are shown in *Table A10:2*. Where the technology developer did not supply the requested device spacing, it was not possible to calculate the number of devices that could be utilized.

The reader is referred to *Appendix 10* for the more details about the calculations. The values shown in the table do not take into account fjord specific depth limitations (L_d=0).

Using the rated power for each device and the number of devices that can be utilized, the estimated annual energy production was determined for the different technologies, fjord crossing locations and bridging technologies using the assumed capacity factor of 40%. The results shown in *Table A11:1* show the annual energy production in (GWh/year) for the suspension bridge or floating bridge designs ($E_{sus/float}$) and the results shown in *Table A11:2* show the annual energy production for the submerged floating tunnel design (E_{SFT}). The different fjord crossings are represented by the crossing number shown in *Table 1.* Where the technology developer did not supply device spacing requirements or the rated power of the device, no calculation of the annual energy production was performed.

Table A11:1 and *Table A11:2* show that there is a large range of estimated annual energy production from the different technologies. This is in large part due to the variation in the different technology types, sizes of the devices and the wave resources in which the devices are rated. Because there is no available information about the wave resources, a rough approximation of the annual energy production is again determined using the average of the different estimates. Assuming all of the fjord crossing locations have significant tidal resources it can be estimated that the total annual energy production from the WEC devices is between 9.3 and 11.0 TWh/yr (depending on the bridge designs).

When the calculated values are compared to previous annual estimations of the resource in Norway, we see that there is a discrepancy. The previously mentioned study estimated that the maximum total economical resource was around 30 TWh/yr for Norway [16]. Though the presented calculations do not exceed this estimate, the estimate considers offshore locations, where resources are likely greater than they are at the fjord crossing locations of interest.

With the presented calculations overestimating the energy production when compared to previous studies, it can be concluded that at least one of the assumptions made in the calculations is non-conservative. The first potentially non-conservative assumption is that the average of the calculated annual energy productions from the different devices would be representative of the actual possible energy production. As for the TISEC devices, the WEC devices have a large spread in their rated power and the sea state for which they are rated. Also the devices are all at different technology readiness levels causing there to be different levels of uncertainty in their estimated performance. The other potentially non-conservative assumption is that the WEC devices will be able to achieve capacity factors of 40% in the locations of the fjord crossings. Unfortunately with no wave resource data for the fjords of interest available it is not possible to estimate what accurate capacity factors of the different devices are.

11.4 Wave energy recommendations

Without wave resource data for the particular locations of the proposed fjord crossings, it is not possible to calculate realistic estimates of what the potential energy output is from combining the WEC devices with the bridging technologies. Additionally, with no available wave resource data, the WEC developers did not have the possibility to optimize their devices according to the wave conditions for the particular fjord crossing locations. This means that it is not possible to use the results from the previous section when making recommendations about which technologies would provide the most energy for the crossing locations. It is therefore recommended that the next step is to obtain more wave resource data for all of the fjord crossing locations.

The wave resource data could initially be obtained from models, which should be able to provide accurate enough information to see if the wave resources at the particular fjord crossing location are significant enough to be considered further. If the models show that the wave resources are significant, then experimental data should be gathered at the fjord crossing locations in order to verify the results from the models. Data should include both the significant wave height and the peak wave period. Again, the experimental data should be gathered over a significant period of time to ensure that the models reliably take into account seasonal variations in the wave resources.

With detailed information about the annual distribution of the significant wave height and the peak wave period available, the developers should be contacted and asked to optimize the designs of their devices according to the wave resources at the fjord crossing locations of interest. At that point any necessary non-discloser agreements should be signed in order to gain access to proprietary information about the performance of the WEC devices.

Once the designs have been optimized and updates have been made to the wave power absorption performance matrices, the calculation methods described in section 11.3.1 can be utilized to determine realistic estimates of the energy production for the different technologies. Using this detailed information, comparisons can be made between the different technologies, and recommendations can be made. The recommendations can include information about whether or not the WEC device power plants are viable and about which technology, or combination of technologies will be most effective for the different fjord crossing locations if the power plants are viable.

12 Combining multiple renewable energy technologies

Within the Ferry Free E39 project, several different renewable energy technologies are being simultaneously considered. This report discusses the potential of combining tidal and wave energy conversion devices with the bridging technologies at the various fjord crossing locations. Because both the tidal and wave energy conversion devices need access to the water in the area surrounding the bridge structure, there will likely be conflicts over the available area around the structure. More than likely compromises will need to be made and bridges will not be able to utilize both tidal and wave energy conversion devices in the same sections of the bridge. When the wave and tidal resources are better known, optimal solutions can be better determined.

When considering combining wave or tidal energy conversion devices with wind and solar energy conversion technologies, both conflicts and synergy effects can be envisioned. The reader is refered to SP’s Solar and Wind energy technology surveys for the Ferry Free E39 project, which give detailed information about how solar and wind energy conversion devices can be combined with the bridging structures [30] [31]. If it is decided to use additional structures to increase the number of potential tidal or wave energy conversion devices in the downstream direction, then the available area for solar cells can be greatly increased. The additional structures could even be formed to help increase the wind velocity seen by the wind conversion technologies. Of course the optimization of the designs will depend on the relative available resources at each of the different locations and goes beyond the scope of the present study.

13 Summary and conclusions

In order to determine the feasibility of combining the proposed fjord crossing solutions for the Ferry Free E39 project with renewable energy power plants, the current state of the art of the renewable energy technologies must be reviewed and realistic estimations of the potential energy that could be obtained from the fjord crossings must be made. This report describes the background of the project and the requests for information questionnaires that were developed and sent to the tidal and wave energy technology developers. The result of survey is a comprehensive and up to date collection of information about the tidal and wave energy technology developers who are are potential partners for later stages in the Ferry Free E39 project. The information is presented in table format allowing for comparisons to be easily made between the different technologies.

This report also describes the concepts that developers suggested for how their devices could be attached to the different bridging structures and the advantages and disadvantages of the different concepts. Additionally, concepts were presented which allow the number of devices that can be utilized at the various fjord crossings to be maximized. Methods to calculate the energy that could be obtained by employing wave and tidal energy conversion technologies are also discussed.

Unfortunately, a lack of tidal and wave energy resource data at the fjord crossing locations made it impossible to utilize the detailed calculation method that was described and a simplified calculation method was used to calculate rough estimates of the energy potential from the different devices. When the estimates were compared to previous studies it showed that the estimates based on the simplified approach were non-conservative. Source of non-conservatism in the calculations were discussed and it was concluded that the next stage of the study should concentrate on obtaining reliable data about the tidal and wave energy resources for the different fjord crossing locations. The data should be obtained over a significant period of time to ensure that the effects of seasonal variations in the resources are captured.

Once tidal and wave resources data is available, more realistic calculations of the potential energy production can be completed. At that point, comparisons of the performance of the difference technologies can be made.

From that point, more detailed studies should be undertaken where the concepts for combining the devices with the bridging technologies are optimized. This optimization should include actions such as loads analysis, structural strength calculations, reliability and fatigue performance evaluations and detailed cost estimates.

14 References

[1] Zabihian F, Fung AS. Review of marine renewable energies: Case study of Iran. Renewable and Sustainable Energy Reviews 2011;15:2461-2474.

[2] Yun Seng. Lim and Siong Lee. Koh (2009). Marine Tidal Current Electric Power Generation: State of Art and Current Status, Renewable Energy, T J Hammons (Ed.), ISBN: 978-953-7619-52-7, InTech, Available from: http://www.intechopen.com/articles/show/title/marine-tidal-current-electric-power-generation-state-of-art-and-current-status

[3] Comission, E., Ocean energy conversion in Europe: Recent advancements and prospects. 2006, Centre for Renewable Energy Sources: Pikermi, Greece.

[4] Fujita Research - Wave and tidal power. http://www.fujitaresearch.com/reports/tidalpower.html. Retrieved February 15, 2012.

[5] Spain R. A possible Roman Tide Mill. Paper 005. Kent Archaelological Society 2002.

[6] Ryckaert M. Olhao Tide Mill.jpg. http://en.wikipedia.org/wiki/File:Olhao_Tide_Mill.jpg. Retrieved February 15, 2012. Under the Creative Commons Attribution 3.0 Unported license. More information on this license is available at http://creativecommons.org/licenses/by/3.0/.

[7] Rourke FO, Boyle F, Reynolds A. Tidal energy update 2009. Applied Energy 2010;87:398-409.

[8] The original Bay of Fundy website. http://bayoffundy.com/about/highest-tides/. Retrieved February 15, 2012.

[9] Bedard R. Survey and characterization - tidal in stream energy conversion (TISEC) devices. EPRI TP-004 NA; November 2005.

[10] Bahaj AS, Myers L. Analytical estimates of the energy yield potential from the Alderney Race (Channel Islands) using marine current energy converters. Renewable Energy 2004;29:1931-1945.

[11] T. J. Hammons (2009). Tidal Energy Technologies: Currents, Wave and Offshore Wind Power in the United Kingdom, Europe and North America, Renewable Energy, T J Hammons (Ed.), ISBN: 978-953-7619-52-7, InTech, Available from: http://www.intechopen.com/articles/show/title/tidal-energy-technologies-currents-wave-and-offshore-wind-power-in-the-united-kingdom-europe-and-nor

[12] Grabbe M, Lalander E, Lundin S, Leijon M. A review of the tidal current energy resource in Norway. Renewable and Sustainable Energy Reviews 2009;13:1898-1909.

[13] Johnson JB, Pride DJ. River, Tidal, and Ocean Current Hydrokinetric Energy Technologies: Status and Future Opportunities in Alaska. 2010, Alaska Center for Energy and Power.

[14] UK, Europe and global tidal stream energy resource assessment. Black Veatech Ltd.; September 2005.

[15] Fröberg E. Current Power Resource Assessment - A study of selected sites in Sweden and Norway. Master's thesis. Uppsala University; September 2006.

[16] Potensialstudie av havenergi i Norge. SWECO Grøner. Report 154650-2007.1, Enova SF; October 2007.

[17] The European Marine Energy Centre (EMEC) Ltd website. http://www.emec.org.uk/. Retrieved February 15, 2012.

[18] The U.S. Department of Energy - Marine and Hydrokinetic Technology Database website. http://www1.eere.energy.gov/water/hydrokinetic/default.aspx. Retrieved February 15, 2012.
[19] Lunar Energy official website. http://www.lunarenergy.co.uk/productOverview.htm. Retrieved February 15 2012.
[20] Rahm M. Ocean Wave Energy - Underwater Substation System for Wave Energy Converters. PhD thesis. Uppsala University; March 2010.
[21] de O. Falcão AF. Wave energy utilization: A review of the technologies. Renewable and Sustainable Energy Reviews 2010;14(3):899-918.
[22] Siegel SG, Fagley C, Römer M, Mclaughlin, TE. Experimental Wave Cancellation using a Cycloidal Wave Energy Converter. Proceedings of the 9th European Wave and Tidal Energy Conference, Southampton, UK, 5th-9th September 2011.
[23] Hagerman G, Bedard R. Guidelines for Preliminary Estimation of Power Production by Offshore Wave Energy Conversion Devices. E2I EPRI-WP-US-001; December 2003.
[24] Google Mpas. http://maps.google.com. Retrieved March 9, 2012.
[25] Mulighetsstudie – Kryssing av Sognefjorden – oppsummering etter idéfasen, Statens vegvesen Region vest, Versjon 23.03.2011.
[26] Bedard R, Previsic M. Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices. EPRI TP-001 NA Rev 3; September 2006.
[27] Gjevik B, Gundersen E, Sandbo H. Vudering av potensialet for kraftproduksjon i forbindelse med bruer langs ferjefri E39. Arbeidsutkast, 2012-03-14.
[28] Lindberg U, Probability estimate of ship collision with planned E39 bridges, SSPA Report No.:20126158, SSPA Sweden AB, March 5, 2012.
[29] Ferjefri E39 – bru over Bjørnafjorden, Jan Soldal/Akvator AS, Multiconsult AS, LMG Marin AS, Sintef/Marintek, February 2012.
[30] Kovacs P, Wahlgren P, Solar energy technology survey for Ferry Free E39 project, SP, Borås Sweden, March 2012.
[31] Åkesson L, Wind energy technology survey for Ferry Free E39 project, SP, Borås Sweden, March 2012.

Appendices

1. TISEC device request for information
2. TISEC device list of developers
3. TISEC device responses
4. WEC device request for information
5. WEC device list of developers
6. WEC device responses
7. Fjord crossing locations
8. Calculations of the number of TISEC devices
9. Calculation of the energy from TISEC devices
10. Calculations of the number of WEC devices
11. Calculation of the energy from WEC devices

Appendix 1: TISEC device request for information

Dear Sir or Madam:

SP Technical Research Institute of Sweden has been commissioned by the Norwegian Public Roads Administration in a project that will potentially utilize a large number of tidal in stream energy conversion devices. We are currently in the process of performing a technology survey to determine the capabilities and characteristics of the different devices that are being developed. Upon review of the information available on the internet it seems that your technology is potentially promising for our application. We have developed a short questionnaire that we are asking all companies of interest to fill out in order to have an up-to-date basis for comparison of the different technologies. We would appreciate it if you could take the time to fill out the table below and send it back to me before 2012-01-31. If any of the information is not currently available then simply state that in your reply. A fictional sample reply is provided for your convenience and more information about some of the questions is given in the information below. I have also attached a copy of the questionnaire in excel format if you have any problems with the formatting of the table in the email when you reply.

For more information about the background of the project itself, please see the information below*. The results of this technology survey will be presented as part the workshop/conference scheduled for April 2012 (probably in Trondheim, Norway).

If you have any questions about the questionnaire or if you would like more detailed information about the project then feel free to contact me by replying to this email or calling at the number given below.

Best regards,

Daniel

Daniel Vennetti

SP Sveriges Tekniska Forskningsinstitut
SP Technical Research Institute of Sweden
Byggnadsteknik och Mekanik/Buildning Technology and Mechanics
Box 857, SE-501 15 Borås, Sweden
Tel: +46 (0)10 516 50 00, (direct) +46 (0)10 516 57 83
E-post: daniel.vennetti@sp.se
Internet: www.sp.se

	Fictional Sample Reply
Company	SP - Technical Research Institute of Sweden
Country	Sweden
Web address	http://www.sp.se/en/Sidor/default.aspx
Technology Name	SP Tidal Technology
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	iii (Flexible mooring)
Is power generated during ebb and flood flows	Yes
Features / Design principle	SP Tidal Technology has three unshrouded horizontal axis turbines that are attached to a floating platform that has a flexible mooring system. The flexible mooring allows the platform to swing as the tidal direction changes so that power is generated with equal efficiency in both ebb and flood flows.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:10 scale proof-of-concept model was tested at SP's wave laboratory in Borås Sweden 2007-10. A 1:5 scale model including the floating platform and flexible mooring devices was tested at SP's Big wave test facility in Borås, Sweden 2009-11. A full scale model is currently being tested including the floating platform and flexible mooring system in the SP slow fjord in Borås, Sweden which has maximum flow speed of 1.5 m/s. The full scale model was deployed 2010-06 and has been generating power to the grid for over 4000 hours.

Next development steps	We have a spot reserved at the SP fast fjord test facility in Borås, Sweden which has a maximum flow speed of 3.0 m/s. Testing is expected to begin in 2012-07
Power train type	Direct drive generator
Dimensions	Each of the three turbines has 2 rotors with a 20 m diameter. The floating platform itself is 100 m wide x 100 m deep and has a height of 3 m. the bottom 1 m of the platform will be under the water level.
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	942
Weight of super structure (ton)	75
Weight of power take off equipment (ton)	100
Min installation depth (m)	30
Max installation depth (m)	100
Design lifetime (years)	15
Cut in speed (m/s)	0.7
Rated flow speed (m/s)	3
Rated power (kW) at rated flow speed	4000
Maximum flow speed (m/s)	3.5
Current speed (m/s) vs electric power output (kWe) data points	See below
Estimated date commercially available	2015-01
Estimated production cost per rated unit (EUR)	5.00E+06
Have environmental impact studies been performed	Yes
Technical publications	Vennetti D. Power predictions of the SP Tidal Technology,. Renewable Energy Review 2007;5(5)20-50. Vennetti D. SP Tidal Technology Environmental Impact Study,. Environment Magazine 2011;2(20)15-35.
Figures/photographs of device have been attached to reply	Yes (not actually true for this fictional example)
Could the device be combined with a suspension bridge fjord crossing / how?	Yes, the mooring lines could be attached to an overhanging suspension bridge. This configuration was tested with the 1:5 scale model described above.

Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	For a deep water fjord, connecting the mooring lines to an overhanging bridge would be an advantage because the main limitation on the depth of the design is due to a maximum permissible length of the mooring lines. Using an overhanging bridge, the fjord could be infinitely deep. Another advantage of attaching the mooring lines to an overhanging bridge would be that the attachment point could be designed into the bridge structure, which saves time and money that is spent in a traditional installation attaching the mooring lines to the seabed. One disadvantage is the additional horizontal load on the bridge structure from reacting the force absorbed by the device.
Could the device be combined with a floating bridge fjord crossing / how?	Yes, the mooring lines could be attached to the overhanging bridge assuming that there is enough clearance between the pontoons for the platform to turn around when the tides change direction.
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Based on the clearance between the pontoons, a special device may need to be designed that allows the platform to rotate when the tides change direction. The effects of the pontoons on the flow characteristics around the device would have to be evaluated to ensure that the device performance is not negatively affected. A disadvantage would again be the additional horizontal load on the bridge structure from reacting the force absorbed by the device.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes, depending on the submerged depth of the floating tunnel, our platform should be able to be combined to a submerged floating tunnel because it in principle would be the same as attaching the mooring lines to the ocean floor.

Advantages / disadvantages of combining the device with a submerged floating tunnel fjord crossing	The main advantage is that it would be cheaper to install the device because an attachment point could be designed into the tunnel geometry, which saves time and money that is spent in a traditional installation attaching the mooring lines to the seabed. The disadvantage again would be the additional horizontal load on the supporting structure caused by reacting the force absorbed by the device.

Current Speed (m/s)	**Electric Power Output (kWe)**
0.7	59
0.8	89
0.9	125
1	172
1.1	219
1.2	285
1.3	362
1.4	475
1.5	611
1.6	759
1.7	910
1.8	1080
1.9	1214
2	1416
2.1	1524
2.2	1735
2.3	2029
2.4	2304
2.5	2605
2.6	2930
2.7	3135
2.8	3497
2.9	3614
3	4000
3.1	4000

3.2	4000
3.3	4000
3.4	4000
3.5	4000

* **Project Background**
E39 is a road that is located on the west coast of Norway and extends from Kristiansand in the south to Trondheim in the north. Currently, a number of ferry crossings are required to traverse its entire length. The Transport Ministry has given a mandate for the project "Ferry Free E39" to assess the technological solutions for the crossing of eight large fjords without ferries. The fjords crossings range from 1.5 km to 25 km in length and have depths up to 1300 m. Proposed solutions for the crossings that are under consideration consist of suspension bridges, floating bridges, submerged floating tunnels, and sub-sea rock tunnels. Part of the project is to consider how the construction of the crossings can be combined with devices that produce energy from waves, tides, wind and the sun. The idea is that by using the bridge construction as part of the facility, the costs of the renewable power plants could be reduced and therefore be more competitive with non-renewable energy sources.

Questionnaire Information
**** Device Type and Method to fix the device**
More information about the classification of device types and methods to fix the device can be found at the European Marine Energy Centre (EMEC) website at the following address:

http://www.emec.org.uk/tidal_devices.asp

***** Development status**
The development status of the project should be classified using the following technology readiness levels, which were obtained from the U.S. department of energy website at the following address:

http://www1.eere.energy.gov/water/hydrokinetic/usingDB.aspx

TRL 1-3: Discovery / Concept Definition / Early Stage Development, Design and Engineering

TRL 1-2: These are the lowest levels of technology readiness. Scientific research begins to be translated into applied research and development where basic principles are observed and reported. Technology concept and application are formulated and investigated through analytic studies and in-depth investigations of principal design considerations. This stage is characterized by paper studies, concept exploration, and planning.

TRL 3: In this stage, active research is initiated, including engineering studies and laboratory studies to physically validate analytical predictions of separate elements of the technology.

The purpose of this stage is to evaluate, insofar as possible, the scientific or technical merit and feasibility of ideas that appear to have commercial potential.

TRL 4: Proof of Concept
In this stage basic technological components of a sub-scale model are integrated to validate design predictions and system level functionality. The models, or critical subsystems, are tested in a laboratory environment.

This TRL represents early stage proof-of-concept system or component development, testing and concept validation. In this stage, critical technology elements are developed and tested in a laboratory environment. It is envisioned that scale models will be at 1:10 scale or smaller.

TRL 5/6: System Integration, and Technology Laboratory Demonstration

TRL 5: At this level, basic technological components are fabricated at a scale relevant to full scale and integrated to establish and verify subsystem and system level functionality and preparation for testing in a simulated environment.

TRL 6: At this level, representative model or prototype system at a scale relevant to full scale, which is beyond that of TRL 5, is tested in a relevant environment. This stage represents a major step up in a technology's demonstrated readiness and risk mitigation and is the stage leading to open water testing.

At this stage device, system, and subsystem level interfacing/integration testing represent a vital stage in technology development, and must be demonstrated. Models should be at a relevant scale (1:1 – 1:5) to reflect the challenges and realities of the full scale (1:1) system. Model testing is to be performed in a test facility capable of producing simulated waves/currents and other operational conditions while monitoring device response and performance. Furthermore, the devices foundation concept shall be incorporated and demonstrated.

TRL 7/8: Open Water System Testing, Demonstration, and Operation

TRL 7: At this level, the prototype scale components and subsystems are fabricated and integrated to establish and verify subsystem and system level functionality and preparation for testing in an open water operational environment to verify expected operation and fine tune the design prior to deployment in an operational demonstration project.

TRL 8: At this level, the prototype in its final form (at or near full scale) is to be tested, and qualified in an open water environment under all expected operating conditions to demonstrate readiness for commercial deployment in a demonstration project. Testing should include extreme conditions.

At this stage, the device model scale is expected to be at or near full scale (1:1 – 1:2). Testing may be initially performed in water at a relatively benign location, with the expectation that testing then be performed in a fully exposed, open water environment, where representative operating environments can be experienced. The final foundation/mooring design shall be incorporated into model testing at this stage.

DOE TRL 9: Commercial-Scale Production / Application

At this stage, the actual, commercial-scale system is proven through successful mission operations, whereby it is fielded and in-use in commercial application. This stage represents an in-service application of the technology in its final form and under mission condition

Appendix 2: TISEC device list of developers

Table A2:1 TISEC device developers.

Technology Developer	**Confirmed Contact**	**Responded to RFI**
Alstom Hydro		
Aquantis Inc		
Atlantis Resources Corp		
Atlantisstrom		
Aquascientific		
BioPower Systems Pty Ltd		
Blue Energy		
Bluewater		
Bourne Energy		
Cetus Energy		
Clean Current Power Systems		
Current2Current		
Current Power AB		
Ecofys		
Firth Tidal Energy		
Flumill		
Free Flow 69		
Free Flow Power Corporation		
GCK Technology		
Greener Works Limited		
Hales Energy Ltd		
Hammerfest Strom		
Hydra Tidal Energy Technology AS		
Hydro Green Energy		
Hydro-Gen		
Hydrokinetic Laboratory		
Hydrovolts Inc		
Kepler Energy		
Lucid Energy Technologies		
Lunar Energy		
Magallanes Renovables		
Marine Current Turbines		
Minesto		
Natural Currents		
Nautricity Ltd		
Neptune Renewable Energy Ltd		
New Energy Corp.		
Norwegian Ocean Power		
Ocean Flow Energy		
Ocean Renewable Power Company		

Oceana Energy Company		
Offshore Islands Ltd		
OpenHydro		
Ponte di Archimede		
Pulse Tidal		
Scotrenewables		
SMD Hydrovision		
Swanturbines Ltd.		
Tidal Electric		
Tidal Energy Ltd		
Tidal Energy Pty Ltd		
Tidal Generation Limited		
Tidal Sails		
TidalStream		
Tide Tec AS		
Tideng		
Tocardo BV		
UEK Corporation		
Verdant Power		
VerdErg		
Voith Hydro		
Vortex Hydro Energy		
Water Wall Turbine		

Appendix 3: TISEC device responses

Table A3:1 TISEC device basic information.

Technology Developer	**Technology Name**	**Device Type**	**Country**	**Rated Power (kW)**
Atlantis Resources Corp	AR series / AS series	A	UK / Singapore	1000
BioPower Systems Pty Ltd	bioSTREAM	C	Australia	250
Hales Energy Ltd	Hales Tidal Stream Turbine	E	UK	-
Hammerfest Strom	-	A	Norway	300-1000
HPS AS	Tideng	B / E	Denmark	1000
Hydro-Gen	Hydro-gen	A	France	40
Kepler Energy	THAWT	B	UK	4600
Nautricity Ltd	CoRMaT	A	UK	500
Neptune Renewable Energy Ltd	-	B	UK	400
Norwegian Ocean Power	Pulsus Turbine	E	Norway	600-2500
Ocean Flow Energy Limited	Evopod	A	UK	35-1000
Ocean Renewable Power Company	TidGen™, OCGen™	B	USA	180
Tidal Energy Pty Ltd	DHV Turbine	B / D	Australia	120-5500
Tidal Generation Limited	TGL 1MW Turbine	A	UK	1000
Tidal Sails AS	TidalSails	E	Norway	10000
Tide Tec AS	TideTec energibru konsept	D	Norway	-
Tocardo BV	T100, T200	A	Netherlands	43-174
Verdant Power	KHPS	A	USA	56-500
Voith Hydro	HyTide	A	Germany	1000

In the table, the device types are identified as follows: A= Horizontal axis turbine, B=Cross-axis turbine, C= Oscillating hydrofoil, D=Enclosed Tips (Venturi) and E = Other designs.

Company	Atlantis Resources Corporation ("Atlantis")
Country	United Kingdom HQ/Singapore HQ
Web address	www.atlantisresourcescorporation.com
Technology Name	AR™ series and AS™ series tidal power turbines
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	(i), (ii) or (iii). Atlantis has experience of gravity based foundations (for the AR1000™ at EMEC), piled foundations (at our test site in San Remo, Australia) and floating systems from our tow tests of the AS™ series turbines in Singapore and Australia. Atlantis believes that the foundation solution should be selected according to the unique site conditions and our portfolio of technology allows us to retain this flexibility of approach with respect to final foundation design .
Is power generated during ebb and flood flows	Yes
Features / Design principle	The AR™ series turbines are open ocean devices, designed for robust and reliable performance in wind and wave swept sites. The turbines are open, unshrouded horizontal axis devices with three mono-directional blades and a 180^{o} yawing capability for ebb and flood generation and seasonal heading optimisation. Fixed pitch rotors with winglets to reduce tip losses deliver reliable performance across the flow velocity distribution of a given site and an active pitch system is used for tubrine survival mode to reduce overall system loading. The AR series tubrines use a Permanent Magnet Generator with a single stage gearbox to maximise efficiency and reliability.These devices are typically seabed mounted, either on piled or gravity foundations. The AS™ series turbines are more suited to sheltered locations as they incorporate a shroud structure to reduce tip losses from the rotor blades and increase the velocity flow of water through the three bladed turbine. The blades are bi-directional in design and so this device incorporates no rotate (yaw) function and is well suited for integration in permanent civil engineering structures.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	AR™ series: TRL 8 AS™ series: TRL 7

Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	The AR1000™ was connected to grid at the European Marine Energy Centre (EMEC) in August 2011. This is a full depth, open ocean site in the North Sea, representative of the most challenging conditions to which turbines will be subjected in commercial arrays. The turbine is the first full scale 1 MW turbine (rated at 2.65 m/s) to be connected at such an open ocean site in Scottish waters. In 2008 the AS400™ was extensively tow tested in Australia and Singapore and the high efficiencies were independently verified by Black and Veatch. The AS™ series control system and operating methodology has much in common with the AR1000™ system as tested at EMEC. ARC has been selected as the technology provider of choice in both of the world's largest tidal power projects, including the Pentland Firth 400MW flagship project, MeyGen and the Gulf of Kutch 250MW flagship project, Mundra Tidal Power. The AR series tubrine systems have been selected by governments in Asia, Nth America and Europe as the platform for full scale demonstration programs. Of particular note, Atlantis is the technology partner of the Clearwater Consortium, a consortium of predominentaly Dutch companies including Royal Haskoning, IHC Merwede & Ballast Nedham who are working on developing a similar project in the Amsterdam Surge Barrier, the Oosterscheldte (Eastern Scheldt Barrier) in the Zeeland Province, Holland. This group of experienced hydro/civil engineers and technology companies possess a particularly relevant set of skills in the design, integration, manufacture and installation of a hydro-kinetic solution in combination with planned civil infrastructure. We would be delighted to offer you more information on the skills, service and product offerings of the Clearwater Consortium upon request.
Next development steps	The AR1000 will be the first full scale system to be tested at the UK's National Renewable Energy Centre (NaREC) in 2012. Due to customer demand, Atlantis will commence detailed design on a 1.5MW and 2.0MW drive train system for the AR series turbines during 2012, due for open ocean testing in 2013. A berth has been awarded to ARC at the Fundy Ocean Research Centre for Energy in Canada which we seek to develop in 2012/13, and other full scale demonstration projects are planned in Italy,

	China and the Netherlands. These form an integral part of ARC's path to a warranted commercial product.
Power train type	The ARC turbines are currently fitted with single stage gearboxes connected to a PMG. The single stage gearbox is used to to step up the rotational speed for the permanent magnet generator. The current systems is rated at 1.0 MW @ 2.65 m/s. A full study is underway to evaluate the relative costs and benefits of transitioning to a direct drive system with some of the world's leading developers of Direct Drive PMGs. Atlantis has already commenced work on offering the AR drive train platform in 1.5 MW & 2.0 MW configurations which will be capable of being adjusted to rated velocity or rotor diameter, depending on the bathymetry and flow velocity distribution profile at each particular project site. The current AR1000 Mark 1 EMEC tubrine is a 1MW drive train rated at 2.65 m/s.
Dimensions	The optimal turbine rotor size is chiefly dependent on water depth and flow regime, and so is selected according to the specific site conditions. The 1MW AR1000™ EMEC turbine has an 18m rotor diameter and is typically positioned at least 5m above the seabed to avoid the slow moving boundary layer. The EMEC AR1000 turbine has a total height of 23 meters once mounted on its gravity base structure.
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	As discussed, turbine diameter can be varied to suit site conditions. The AR1000™ has a swept area of 254m^2.
Weight of super structure (ton)	Total Turbine System weight 1500T including Gravity Base and Ballast Gravity Base structure - 180T Turbine Super structure - 80T
Weight of power take off equipment (ton)	40T
Min installation depth (m)	25
Max installation depth (m)	60 (This is a maximum submersion rather than a limiting total water depth)
Design lifetime (years)	20
Cut in speed (m/s)	0.65
Rated flow speed (m/s)	2.65

Rated power (kW) at rated flow speed	1000* (*1.5MW drive train system to ve available in 2013)
Maximum flow speed (m/s)	Survival Condition - 4.3m/s peak tidal flow combined with 10.2m Hmax wave (5.2m/s combined with 13.5 Hmax as of 2013)
Cut out speed (m/s)	3.4 (4.5 as of 2013)
Current speed (m/s) vs electric power output (kWe) data points	See below for AR1000™
Estimated date commercially available	2013-01 (9 month delivery time on long lead items)
Estimated production cost per rated unit (EUR)	3.40E+06
Have environmental impact studies been performed	Yes. No negative impact has been recorded on local flora and fauna for any ARC installation.
Technical publications	PCT/AU2004/001281, PCT/AU2008/001737, PCT/AU2010/000618, PCT/AU2009/000457, PCT/AU2009/000458, PCT/IB2010/001364, PCT/AU2010/001161,PCT/AU2010/001427, PCT/IB2010/001346,PCT/AU2010/001426, PCT/AU2011/001009, 2011901759
Figures/photographs of device have been attached to reply	Yes (in addition - footage of onshore/offshore/sub-sea operations can be found at the Atlantis website)
Could the device be combined with a suspension bridge fjord crossing / how?	Atlantis technologies are designed for deployment flexibility, and can be matched to most installation scenarios. Integrating the turbines with civil structures would require close collaboration with the bridge design team to establish the most cost effective method of securing the turbine. In the most simple scenario the turbine could be suspended from the bridge platform using a rigid frame, such as that used in tow testing of the AS™ series turbines.
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	Raising and lowering of the frame would allow for easy access to the device for maintenance and the bridge itself provides an ideal corridor for routing of power export cables. Vessel costs for both installation and maintenance would be substantially reduced in comparison to a gravity base or piled foundation. The sophisticated proprietary Atlantis control and power conditioning equipment could be housed either on the bridge or onshore to reduce installed cost per MW, improve access and reduce intervention (maintenance) costs as well as maximise overall yield through the reduction of system losses. If the turbine is not bottom mounted, then the depth of water is no longer a limiting factor for installation as the submersion depth can be optimised from the

	surface. Wave and current action on the device will create horizontal and vertical loads which would be transmitted to the bridge structure. The horizontal loads are likely to prove the greater challenge for bridge designers but could, if necessary, be reduced through ancillary structures.
Could the device be combined with a floating bridge fjord crossing / how?	Yes. As pontoon bridges are usually only practicable in relatively sheltered waters, the AS™ device is likely to offer a good solution in this instance. As it is fitted with bidirectional blades there is no requirement for a yawing function, and this facilitates permanent integration into the bridge structure.
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	As with a suspension bridge, the pontoon bridge provides a platform for turbine access and cable routing, again reducing installation and maintenance expenditure. Depending on the requirement for the passage of marine traffic, the pontoon structures could be designed to effectively channel flow through the inter-pontoon turbines, thus increasing energy output. As before, the effect of the turbines will be to increase the overall drag on the structure. The design of the anchor layout can be adapted to ensure that this is adequately resisted.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes. As with the floating bridge, this is likely to be practicable only in a relatively benign flow regime, and so a shrouded turbine, the AS™ series, is recommended to maximise energy output. This could be affixed directly to the seabed as part of the anchoring system for the tunnel, or attached to the tunnel itself, most probably beneath the tunnel. The optimal solution would depend on, among other factors, the water depth.
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	As with the other options, the tunnel provides a useful passageway for cables, though it is likely that these would run along the exterior walls as the watertight integrity of the tunnel itself will be absolutely paramount. This means that access for maintenance is unlikely to be as substantially enhanced as for the bridge structures. The tunnel itself will present an obstruction to the flow which, if profiled appropriately, could increase the flow directed through the turbines, thus increasing energy output.

	However, if the turbines are attached solely to the tunnel they will again serve to create horizontal loading which must be resisted by the anchor spread.

Current Speed (m/s)	**Electric Power Output (kWe)**
0.65	15
0.7	19
0.8	28
0.9	40
1	55
1.1	73
1.2	95
1.3	120
1.4	150
1.5	185
1.6	224
1.7	269
1.8	319
1.9	376
2	438
2.1	507
2.2	583
2.3	666
2.4	757
2.5	856
2.6	963
2.65	1000
2.7	1000
2.8	1000
2.9	1000
3	1000
3.1	1000
3.2	1000
3.3	1000
3.4	1000


AkerSolutions
CSCV 06 L

Note – The remainder of the details of the response from BioPower Systems Pty Ltd are not to be distributed to the general public.

Company	BioPower Systems Pty Ltd
Country	Australia
Web address	www.biopowersystems.com
Technology Name	bioSTREAM
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	C
Rated power (kW) at rated flow speed	250

Company	Hales Energy Ltd
Country	UK
Web address	www.halesenergy.com
Technology Name	HALES TIDAL STREAM TURBINE
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	(E) The Hales Turbine design is a Side Drive Turbine that can operate ducted or open stream. see website www.halesenergy.com
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	i) Gravity Base ii) Pile Mounted iii) Floating structure
Is power generated during ebb and flood flows	YES
Features / Design principle	The patented Hales Turbine design is a vertical axis tidal stream or ROR water turbine that is modelled on the primary principle of a standard water wheel but with special engineering adaptions to allow full rotation under high torque loading while totally immersed.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRH 5/6
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1metre capture area Hales Turbine prototype is at present under trial on the River Thames, England, The test site has tidal flows on the Ebb up to 1.0 m/s. This prototype is housed in a venturi form ducting with a mouth entry area of 3.2 metres. This prototype will form the basis for a modular for of ducted Hales turbine that can be scaled up as requires and sited in many river or shallow tidal locations.
Next development steps	Further test tank design work is programmed at UCL university , London by a Masters student, sponsored by Hales Energy Ltd and also a programmed test tank biuld and test pregramme to scale up the design for large MW sized units deployed by a gravity weighted system.
Power train type	PM generator driven through Epicylic gearbox
Dimensions	Present test pontoon on River Thames is 7.5m x 4m and has an all up weight with ducting of approx 2.5 metric tonne. (the Hales Turbine prototype has an approx weight of 54 Kg).

Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	UNDER DEVLOPMENT
Weight of super structure (ton)	UNDER DEVELOPMENT
Weight of power take off equipment (ton)	UNDER DEVELOPMENT
Min installation depth (m)	UNDER DEVELOPMENT
Max installation depth (m)	UNDER DEVELOPMENT
Design lifetime (years)	25
Cut in speed (m/s)	0.4
Rated flow speed (m/s)	UNDER DEVELOPMENT
Rated power (kW) at rated flow speed	UNDER DEVELOPMENT
Maximum flow speed (m/s)	Design will allow all water flow speeds to be farmed by simple blade changes
Current speed (m/s) vs electric power output (kWe) data points	UNDER DEVELOPMENT
Estimated date commercially available	2013
Estimated production cost per rated unit (EUR)	UNDER DEVELOPMENT
Have environmental impact studies been performed	in process (expect it to be zero)
Technical publications	Nil
Figures/photographs of device have been attached to reply	attached to email
Could the device be combined with a suspension bridge fjord crossing / how?	Yes, A ducted version of the Hales Turbine is a modular unit which is avaiiable for various forms of fixing, only dependent on postion of PM generator which must remain above water and accessable.
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	No problems foreseen, more a case of designing deployment systems to take modular units.
Could the device be combined with a floating bridge fjord crossing / how?	As above
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	The Hales Turbine design is happy to work in turbulant and shallow water so most locations could be used.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	See above

Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	The main advantage is that it would be cheaper to install the device because an attachment point could be designed into the tunnel geometry, which saves time and money that is spent in a traditional installation attaching the mooring lines to the seabed. The disadvantage again would be the additional horizontal load on the supporting structure caused by reacting the force absorbed by the device.

Company	Hammerfest Strøm
Country	Norway
Web address	www.hammerfeststrom.com
Technology Name	
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	i)(Seabed Mounted/Gravity Base)
Is power generated during ebb and flood flows	Yes
Features / Design principle	Ref to attached technical description
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 9
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Ref to attached technical description
Next development steps	Ref to attached technical description
Power train type	Direct connected generator
Dimensions	Ref to attached technicla description
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	To be kept from public acess
Weight of super structure (ton)	Ref ta attached technical description
Weight of power take off equipment (ton)	Ref ta attached technical description
Min installation depth (m)	40
Max installation depth (m)	100
Design lifetime (years)	25
Cut in speed (m/s)	HS300: 0,9 and HS1000: 1,1
Rated flow speed (m/s)	HS300: 1,7 and HS1000: 2,7
Rated power (kW) at rated flow speed	HS300: 300KW and HS1000: 1MW
Maximum flow speed (m/s)	To be kept from public acess

Current speed (m/s) vs electric power output (kWe) data points	To be kept from public acess
Estimated date commercially available	Per to-day
Estimated production cost per rated unit (EUR)	To be kept from public acess
Have environmental impact studies been performed	Yes, continuous
Technical publications	None
Figures/photographs of device have been attached to reply	Ref to our webside
Could the device be combined with a suspension bridge fjord crossing / how?	Technical feasible, depending of the high from the bridge to the sea level.
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	
Could the device be combined with a floating bridge fjord crossing / how?	Technical feasible provided strong enough velocity
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Have not carried out any study of this solution, but avoiding of substrcture and subsea caples and simple maintenance can be an advantages.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Technical feasible
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	A sensible advantage/disadvantage is difficult to give because we haven't investigated this mentioned combinations, but technical feasible, depending on the high from the bridge to the sea level.

Sound of Islay Tidal Energy project

10MW demonstration tidal power array in the sound between the islands of Islay and Jura in Scotland

The Sound of Islay tidal power project is a tidal array of 10MW to be developed in the Sound of Islay, on the west coast of Scotland. The technology is developed and will be delivered by Hammerfest Strøm.

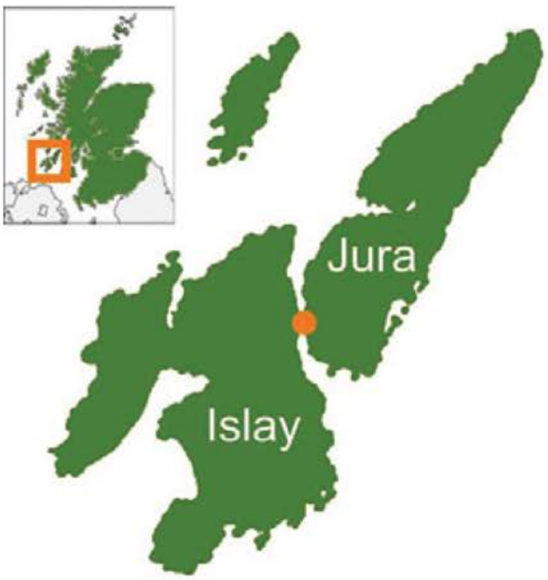
The tidal turbine design has been tested through a 300kW prototype, called the HS300, which was connected to the national grid in Norway in 2004, and a 1MW device – the HS1000, which is to be tested at the European Marine Energy Centre in Orkney in 2011. Following testing at EMEC a 10 device array will be installed in the Sound of Islay in 2013 based on the design of Hammerfest Strøm's HS1000 device.

It is assumed that a significant portion of the construction and assembly for this project will be carried out in Scotland. The substructure for the HS1000, to be installed and tested in Orkney in 2011, is manufactured by BiFab at Arnish and the electrical components are being supplied by Converteam and will be assembled in Glasgow.

The Sound of Islay tidal array will generate around 30GWh per year – enough energy to provide power to the equivalent of approximately 5000 average UK homes. The domestic energy consumption on Islay is approximately 14GWh. The project will also supply energy to industry on Islay.

The project's Environmental Impact Assessment (EIA) is complete and the findings have been included in an Environmental Statement that accompanied the consent applications submitted to Marine Scotland. The EIA covered all aspects of the development including considerations such as potential noise, interaction with marine mammals and birds, visual impact and socioeconomics. Based on other projects and the EIA for the HS300 unit in Norway, and post installation surveys, potential impacts are expected to be minimal.

Planning consent for the project was approved in March 2011.



Device data

General:

Power generation ..3 bladed horizontal axis rotor
Power regulation ....Variable pitch and speed w/power electronics
Net power output....10 x 1MW (at grid connection point)

Operating depths:

Maximum................100m
Minimum.................40m
(Dependent on site characteristics)

Rotor:

Type.........................3 bladed open
Rotor diameter 20-24m
Swept area 314m2- 452m2
Nominal speed 6-11rpm

Generator:

Type.........................Induction
Nominal output.......10 x 1.2MW

Mooring:.................Ballast weights or pinning/micro piles

Installation: ....Standard moored barge or lift DP vessel with ROV support

Design lifetime:.....Service interval for nacelle and rotor is 5 years. Lifetime is 25 years

Project data

Project timeline:

Consent approved March 2011
Planned start of manufacturing 2012
Installation planned for 2013

Location:

Sound of Islay, just south of Port Askaig

Outline:

Turbines arranged in three or four rows in an area 50m deep towards the Islay side of the Sound.

Est. power output:

Around 30GWh per year, or 5000 average UK homes.

Facts

Developer:
ScottishPower Renewables

Candidate Technology:
Hammerfest Strøm

Local partner:
Islay Energy Trust

Size:
10MW (10 x 1MW tidal devices)

Location:
Sound of Islay, Argyll, UK

Timescale:
Installation 2013

HS1000

1MW tidal stream device
The European Marine Energy Centre Ltd. (EMEC), Orkney, Scotland

Hammerfest Strøm is a tidal energy technology company with unrivalled commercial operational experience. It developed and installed the world's first grid connected tidal turbine - the 300kW HS300. The HS300 was installed at Kvalsundet, Finnmark, Northern Norway in 2003, connected to the grid in 2004 and is operated by the utility company Hammerfest Energi. Production capacity today for the HS300 is in excess of 0.5GWh per year.

The company has a clearly defined five stage technology development process for ongoing development for future generations of the device, with the aim of further reducing costs and improving energy efficiencies through incremental design advances, improved installation techniques and reduced marine outage timescales.

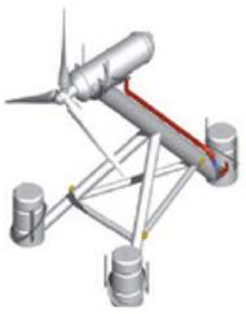
A key stage of this technology development process for Hammerfest Strøm is to gain experience from the installation of a 1MW pre-commercial device - the HS1000 - at EMEC (Orkney, Scotland) planned for 2011.

The objective of the project is to demonstrate the technical and commercial viability of the 1MW tidal generator operating in high tidal flow, high wave and an overall turbulent environment. The HS1000 will have a significant impact on the exploitation of tidal resources around the UK since it can be deployed in a wide range of water depths and water flow speeds.

The project will confirm the robustness and reliability of the device design and the marine installation/deployment methodology. It will also prepare the way for serial production and large-scale deployment, including manufacture of the substructure and nacelle, component supply chain, assembly and deployment, including a testing and commissioning schedule.

ScottishPower Renewables is a strategic partner with Hammerfest Strøm for the delivery of the HS1000 Project at EMEC. In the course of delivering the HS1000 pre-commercial demonstrator for the EMEC test facility, Hammerfest Strøm continues to develop industrial partner relationships in the UK and in Europe for the manufacture of key components, product assembly and marine installation.

HS1000 Technical information



The HS1000 is designed to generate power from water speeds of 1.1m/s or greater. The peak power output of 1MW will be achieved when the water velocity is 2.7m/s or above.

- Proven technology solution
- Proven track record of power delivery to the grid
- Reliable operation and maintenance
- Suitable for use in coastal waters
- Suitable across a range of water depths and velocities
- Simplicity of installation and maintenance

Operating data

General:

Power generation ....Turbine blades pitch to face the tidal flow when the tide reverses
Power regulation ....Variable pitch, variable speed

Rated power 1MW
Rated velocity...................2.7m/s
Cut-in water speed 1.1m/s
Cut-out water speed........4.0m/s

Operating depths:

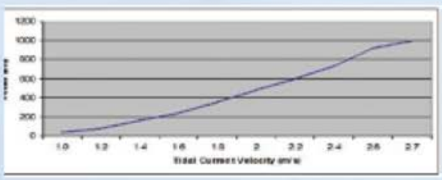
Maximum 100m
Minimum 40m
(Dependent on site characteristics)

Rotor:

Type ....3 bladed open
Rotor diameter.................21m
Swept area 346m2
Nominal speed.................10.2rpm

Generator:

Type ....Induction
Nominal output 1MW



Main device dimensions

Nacelle:

Diameter 3m
Length 10m
Weight .... 134/34T (air/water)

Blade:

Length 8.98m

Substructure:

Width 18.5m
Length 25.5m
Height................. 21.0m
Weight 150/130T
Highest blade tip 32.5m

Installation

Standard heavy lift vessel with ROV support

Array device spacing:

Optimal............... 63m side to side
420m current flow
Minimum............ 42m side to side
210m current flow
Maximum .... N/A

Maintenance and design life

- Maintenance interval every 5 years -
nacelle & rotor require retrieval to surface for service
- 25 year design life

HS300

300kW tidal stream device
Kvalsundet, Finnmark, Northern Norway

Hammerfest Strøm is a tidal energy technology company with unrivalled commercial operational experience. It developed and installed the world's first grid connected tidal turbine - the HS300. The design was based on Norway's experience of hydro power, wind power and oil & gas subsea installations.

The HS300 was installed at Kvalsundet, Finnmark, Northern Norway in 2003, connected to the grid in 2004 and is operated by the utility company Hammerfest Energi.

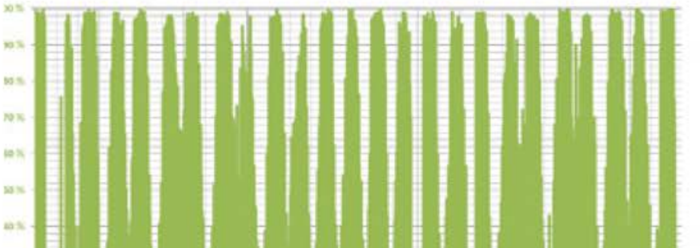
The device has been through a complete retrieval, maintenance and redeployment cycle. It underwent extensive testing during its initial four year deployment prior to a planned maintenance interval where the device was retrieved from the water for inspection and verification.

Since being reinstalled, the device has undergone a test programme focusing on efficiency, free spin behaviour, wake velocity deficit and tower wake effects.

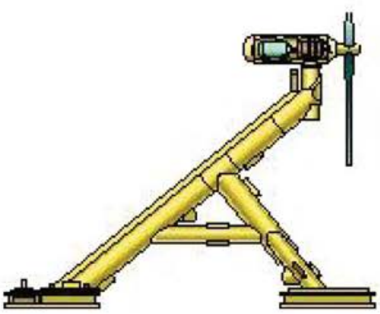
As a result of this prototype device Hammerfest Strøm can boast a track record with over 15,500 hours production time and over 9,000 hours (as at the end of March 2011) continuously in operation since it was put in regular production after reinstallation in early 2010. Production capacity today for the HS300 is in excess of 0.5GWh per year.

Lessons learnt from the HS300 prototype device have informed future design enhancements including; a new fast response pitching mechanism, the extended use of power electronics, modifications to the brake system, upgrading of the monitoring and control systems and more robust marine antifouling solutions. This has also led to the optimisation of installation methods and procedures.

HS300 - 2010/11 Production



HS300 Technical information



The HS300 is designed to generate power from water speeds of 0.9m/s or greater. The peak power output of 300kW will be achieved when the water velocity is 1.7m/s or above.

- Proven technology solution
- Proven track record of power delivery to the grid
- Reliable operation and maintenance
- Suitable for use in coastal waters
- Suitable across a range of water depths and velocities
- Simplicity of installation and maintenance

Operating data

General:

Power generation ....Turbine blades pitch to face the tidal flow when the tide reverses

Power regulation: ....Variable pitch

Rated power:....................300kW
Cut-in water speed: 0.9m/s
Cut-out water speed:.......-
Speed at rated power:......1.7m/s

Operating depths:

Maximum: 100m
Minimum:.........................40m
(Dependent on site characteristics)

Rotor:

Type ....3 bladed open
Rotor diameter:.................20m
Swept area: 314m2
Nominal speed:.................7rpm

Generator:

Type:..................................Induction
Nominal output: 300kW
Power factor range: 0.72

Main device dimensions

Nacelle:

Diameter: 2m
Length:............... 7m
Weight: .... 65/30T (air/water)

Blade:

Length:.............. 8.5m

Substructure:

Width:................. 25m
Length:.............. 32m
Height:................ 19.5m
Weight: 115/100T
Highest blade tip: 31m

Installation

Standard moored barge or heavy lift DP vessel with diver support

Array device spacing:

Optimal:.............. 60m side to side
400m current flow
Minimum:........... 40m side to side
200m current flow
Maximum: .... N/A

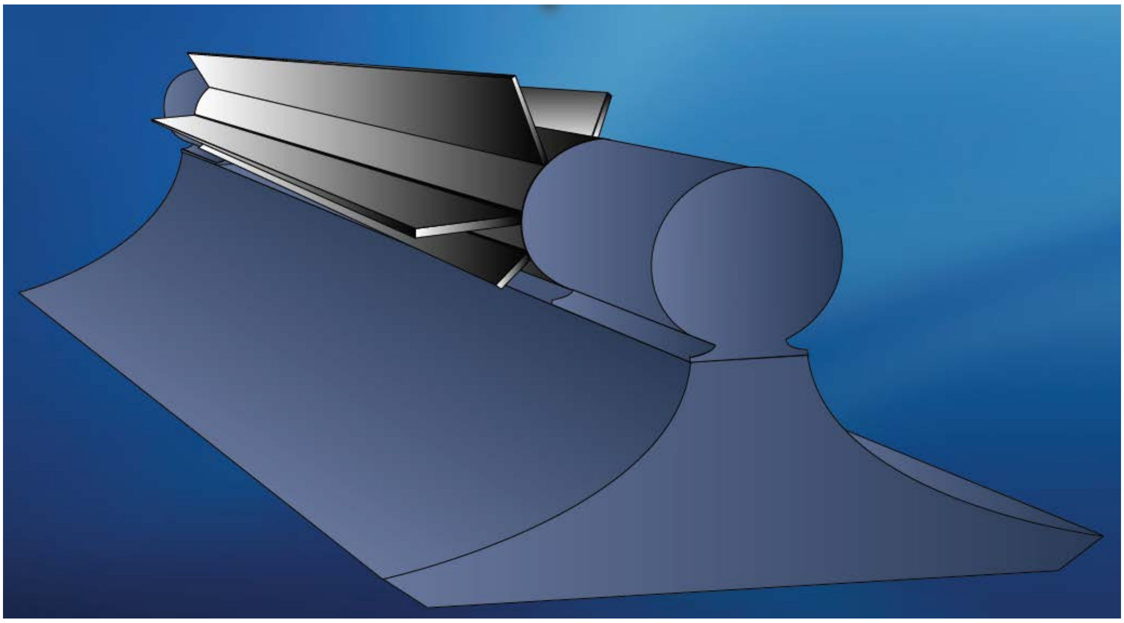
Maintenance and design life

- Maintenance interval every 3 years -
nacelle & rotor require retrieval to surface for service
- 25 year design life

Company	HPS AS
Country	Denmark
Web address	www.hps.as
Technology Name	Tideng
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	B or E
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	i)Gravity Base ii) Pile Mounted
Is power generated during ebb and flood flows	Yes
Features / Design principle	Tideng is a tidal stream and river current energy converter. It is composed by a cross-flow turbine with horizontal axis, supported by a base structure placed on the bottom of the sea. The base, besides providing the necessary stability to the device, enhances the incoming flow speed towards the rotor, which converts the kinetic energy of the flow into electricity. The space is used in an optimal way, making the device a modular unit which can be deployed in arrays or individually. The rotor is the innovative and novel aspect of the device. The blades are connected at both ends to the fixed part of the hub by a joint which is moving along a path grooved in it. This path is designed so that, during the rotation, the blades are forced to move alternatively in and out of the rotor. Tideng is a tidal stream and river current energy converter. It is composed by a cross-flow turbine with horizontal axis, supported by a base structure placed on the bottom of the sea. The base, besides providing the necessary stability to the device, enhances the incoming flow speed towards the rotor, which converts the kinetic energy of the flow into electricity. The space is used in an optimal way, making the device a modular unit which can be deployed in arrays or individually. The rotor is the innovative and novel aspect of the device. The blades are

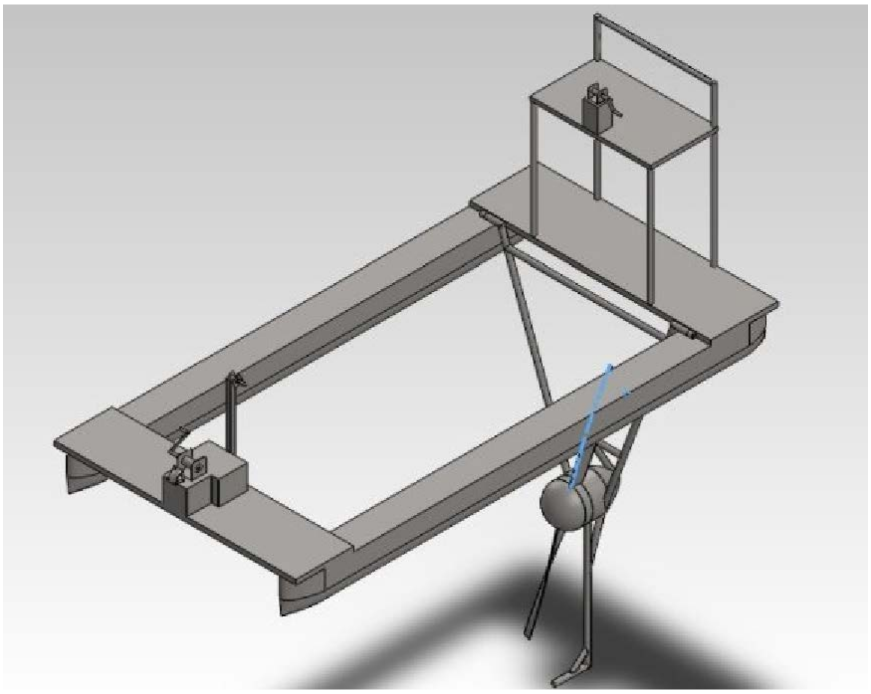
	connected at both ends to the fixed part of the hub by a joint which is moving along a path grooved in it. This path is designed so that, during the rotation, the blades are forced to move alternatively in and out of the rotor. Tideng is a tidal stream and river current energy converter. It is composed by a cross-flow turbine with horizontal axis, supported by a base structure placed on the bottom of the sea. The base, besides providing the necessary stability to the device, enhances the incoming flow speed towards the rotor, which converts the kinetic energy of the flow into electricity. The space is used in an optimal way, making the device a modular unit which can be deployed in arrays or individually. The rotor is the innovative and novel aspect of the device. The blades are connected at both ends to the fixed part of the hub by a joint which is moving along a path grooved in it. This path is designed so that, during the rotation, the blades are forced to move alternatively in and out of the rotor.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Model of device in scale 1:20 has been tested at SINTEF 2007. CDF modeling has been performed by Aalborg University 2010.
Next development steps	Awaiting investors to implement full scale test of 100 kW device.
Power train type	Either direct drive or with gearbox.
Dimensions	Various depending on size of generator up to 3 MW.
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	396 sqm. The Tideng machine can be deployed in different scale. The 1 MW device can have a base 11 meter high including 3 meter rotor blades; Blades 6 meter in diameter and width 32 meter; this giver at a peak velocity of the stream of 4 m/sec a 1MW device with a yearly production of 8.15 GWh
Weight of super structure (ton)	TBD
Weight of power take off equipment (ton)	TBD
Min installation depth (m)	Is depending on size but absolutely min is double the depth of device, in the example above 22 meter
Max installation depth (m)	no max
Design lifetime (years)	50 years

Cut in speed (m/s)	NA, but very low
Rated flow speed (m/s)	4m/sec in a tidal cycle
Rated power (kW) at rated flow speed	1MW / 8.15 GWh
Maximum flow speed (m/s)	NA
Current speed (m/s) vs electric power output (kWe) data points	NA
Estimated date commercially available	2013
Estimated production cost per rated unit (EUR)	0.09 €/kWh
Have environmental impact studies been performed	Yes
Technical publications	Power Production and Economical Feasbility of Tideng Tidal Stream Power Converter; DCE Technical report no. 81 Aalborg University by S. Parmeggiani, P. Frigaard, et. al.
Figures/photographs of device have been attached to reply	yes
Could the device be combined with a suspension bridge fjord crossing / how?	any place upstream
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	Could be part of release system for pillows and cable land fall could be much easier
Could the device be combined with a floating bridge fjord crossing / how?	
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Mooring block of the Tideng could be integrated in the mooring of the floating bridge
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes could be mounted on top of the tunnel
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	Mooring block of the Tideng could be integrated in the mooring of the floating bridge; cable land fall could be easier



Company	Hydro-Gen
Country	France
Web address	http://www.hydro-gen.fr
Technology Name	Hydro-Gen technology
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A)
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	iii) (Flexible mooring)
Is power generated during ebb and flood flows	Yes
Features / Design principle	A floating catamaran barge supporting one or two rotating turbines, so that it can be put easily outside the water for maintenance, cleaning, check, evolution, neutralisation, etc
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL7/8 but limited to 20 kw power
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Several floating turbines prototypes (20 kw) have been tested at sea since 5 years, including paddel wheeels, sliding turbine, etc. Tests are conducted by campaigns of few days or one week.
Next development steps	To have a fully operationnal current turbine in an emerging country (Congo, or Madagascar, or French Guyana)
Power train type	Direct drive generator
Dimensions	on demand and adapted to each situation and site.
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	10
Weight of super structure (ton)	0.6 (600 kg) for a 20 kw turbine
Weight of power take off equipment (ton)	it depends
Min installation depth (m)	4

Max installation depth (m)	1000, but to discuss, as it is just a question of mooring line (id to offshore industry)
Design lifetime (years)	30
Cut in speed (m/s)	0.5
Rated flow speed (m/s)	4
Rated power (kW) at rated flow speed	40 kw on the 20 kw protoype
Maximum flow speed (m/s)	4
Current speed (m/s) vs electric power output (kWe) data points	P=150SV3
Estimated date commercially available	2012
Estimated production cost per rated unit (EUR)	: 0,12 euros/kwh with amortization of the device over 30 years
Have environmental impact studies been performed	not formally, let say just experimentally.
Technical publications	a couple of
Figures/photographs of device have been attached to reply	Yes
Could the device be combined with a suspension bridge fjord crossing / how?	Yes
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	There are advantages if it is possible to attach the device to the bridge structure, as it allows to save the mooring line expense (of course we know the F=f(V) graph in order to study the impact). Another solution is to integrated the rotating turbine to the bridge posts or structure so that there is no need for floats or turbine barge. It saves 2/3 of the total turbine expense. If the above cannot be done, I see it as neutral, as far as I understand the question.
Could the device be combined with a floating bridge fjord crossing / how?	It can possibly be docked to the bridge posts or the structure like a barge at pier.
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	See above, mainly saving money and using the hydrodynamics of the structure (flow put aside but the structure) to increase the current captured by the current turbine (with a power by 3 for the power output).
Could the device be combined with a submerged floating tunnel fjord crossing / how?	I don't see any reason to state No, but it needs to be studied on drawings etc,
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	See above, and all comments related to combine strengths, structures and capturing of the current put aside by an obstacle put in the flow. Clearly it must be studied on the projects design.



Company	Kepler Energy Ltd
Country	UK
Web address	www.keplerenergy.co.uk
Technology Name	THAWT
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	Transverse Horizontal Axis
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	I or ii
Is power generated during ebb and flood flows	yes
Features / Design principle	See website
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	Moving to 5
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:10 scale proof-of-concept model was tested at Newcastle flume in 2011
Next development steps	Build, install and operate a full size protype
Power train type	May be direct drive
Dimensions	Can be manufactured in a variety of diameters up to about 10m. Length would then be 60m, and each unit will have two rotors (to one generator).
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	2X600m for a 10m diameter rotor machine
Weight of super structure (ton)	tbd
Weight of power take off equipment (ton)	tbd
Min installation depth (m)	in theory, very low limit
Max installation depth (m)	Up to about 20-30m. Blockage ratio needs to be about 0.5 to 0.6 which then determines the depths.
Design lifetime (years)	20
Cut in speed (m/s)	?
Rated flow speed (m/s)	2m/sec

Rated power (kW) at rated flow speed	4600 for 10m diameter machine at 2 m/sec. (This is not a prcatical joke!)
Maximum flow speed (m/s)	Currently about 2.5m/sec
Current speed (m/s) vs electric power output (kWe) data points	n/a publicly
Estimated date commercially available	2014
Estimated production cost per rated unit (EUR)	Very competitive!
Have environmental impact studies been performed	No
Technical publications	See below
Figures/photographs of device have been attached to reply	No but see publications
Could the device be combined with a suspension bridge fjord crossing / how?	Yes
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	Need to be aware of blockage effect
Could the device be combined with a floating bridge fjord crossing / how?	Too early to tell
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Too early to tell
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Too early to tell
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	Too early to tell

McAdam, R.A., Houlsby, G.T., Oldfield, M.L.G., 2011, “Structural and Hydrodynamic Model Testing of the Transverse Horizontal Axis Water Turbine”, Proceedings of the 9th European Wave and Tidal Energy Conference, University of Southampton, 5-9 September 2011.

Draper, S., Houlsby, G.T., Oldfield, M.L.G. and Borthwick, A.G.L., 2010, “Modeling Tidal Energy Extraction in a Depth Averaged Domain”, IET Renew. Power Gener., 2010, Vol. 4, Iss. 6, pp. 545–554. doi: 10.1049/iet-rpg.2009.0196 (Also in Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden, 7-10 September 2009).

McAdam, R.A., Houlsby, G.T., Oldfield, M.L.G. and McCulloch, M.D., 2010, “Experimental Testing of the Transverse Horizontal Axis Water Turbine”, IET Renew. Power Gener., 2010, Vol. 4, Iss. 6, pp. 545–554. doi: 10.1049/iet-rpg.2009.0196 (also in Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden, 7-10 September 2009).

Rawlinson-Smith, R., Bryden, I., Folley, M., Martin, V., Stallard, T., Stock-Williams, C. and Willden, R.,2010, “The PerAWaT project: Performance Assessment of Wave and Tidal Array Systems”. In Proc. 3rd International Conference on Ocean Energy (ICOE), Bilbao, Spain.

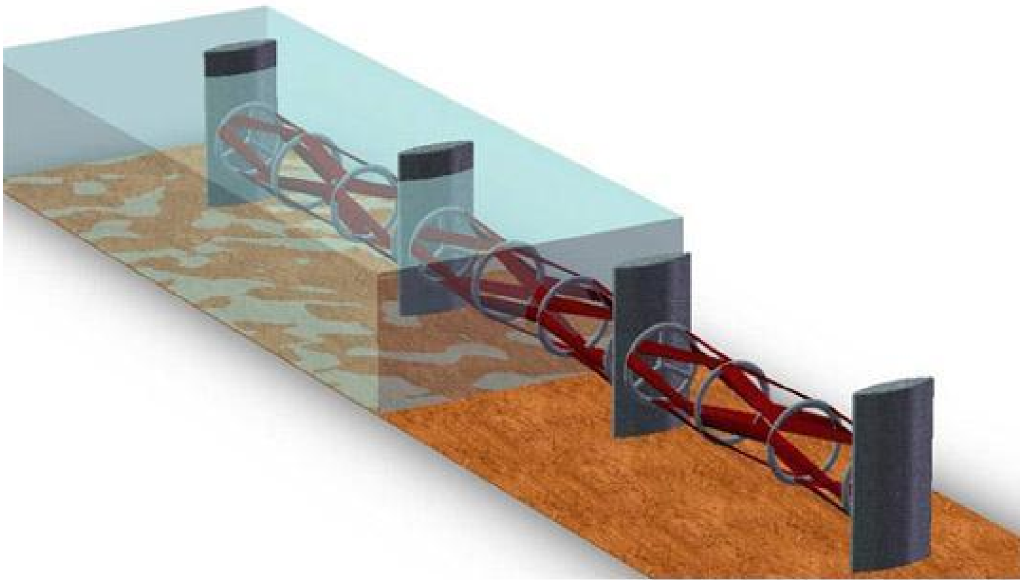
Consul, C.A. & Willden, R.H.J. 2010,.”Influence of Flow Confinement of the Performance of a Cross-Flow Turbine”. In Proc. 3rd International Conference on Ocean Energy (ICOE), Bilbao, Spain.

Belloni, C. & Willden, R.H.J. , 2010. “A computational study of a bi-directional ducted tidal turbine”. In Proc. 3rd International Conference on Ocean Energy (ICOE), Bilbao, Spain.

Consul, C.A., Willden, R.H.J., Ferrer, E. & McCulloch, M.D. , 2009,. “Influence of Solidity on the Performance of a Cross-Flow Turbine”. In Proc. 8th European Wave and Tidal Energy Conference, Uppsala, Sweden.

Houlsby, G.T., Draper, S. and Oldfield, M.L.G., 2008, “Application of Linear Momentum Actuator Disc Theory to Open Channel Flow” Oxford University Dept. Engineering Science Report No. OUEL 2296/08

Houlsby, G.T., Oldfield, M.L.G. and McCulloch, M.D., 2008, “Water Turbine”, British Patent WO/2008/145991 “Water Turbine” filed on 30 May 2007 and published on 04.12.2008.



Source – www.keplerenergy.co.uk

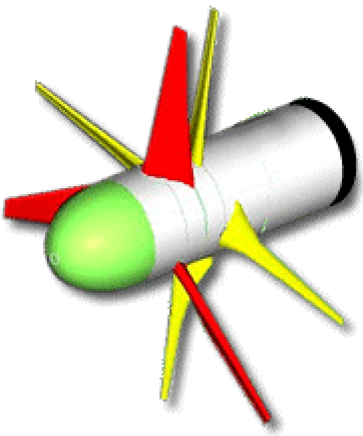
Company	Nautricity Limited
Country	United Kingdom
Web address	http://www.nautricity.com
Technology Name	CoRMaT
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	III
Is power generated during ebb and flood flows	Yes
Features / Design principle	The CoRMaT next generation tidal turbine uses two contra-rotating rotors to directly drive a flooded contra-rotating permanent magnet generator. It's neutral buoyancy enables it to be mounted mid water column in the highest flow velocities with minimum wave interference. Using a flexible tensioned mooring for station keeping enables the device to be deployed in any depth of water, up to typically 500m.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:15 scale proof of concept device was tested in the University of Strathclyde's large tow tank, UK 2005. A 1:7 Scale device was tested in the River Clyde estuary, UK 2007. A prototype system was tested and generated electricity in the Sound of Islay of the West Coast of Scotland, UK 2008. A full scale device is currently in build and due for deployment in the UK late summer 2012.
Next development steps	Development of a 3 MW commercial array to be deployed on sea bed we have secured at the Mull of Kintyre, in the summer of 2014.
Power train type	Direct Drive contra-rotating PMG
Dimensions	Each of the turbine's rotors have a 14m diameter and is rated at 500 kW in flow velocities of 2.5 m/s

Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	154
Weight of super structure (ton)	15
Weight of power take off equipment (ton)	30
Min installation depth (m)	30
Max installation depth (m)	500
Design lifetime (years)	20
Cut in speed (m/s)	1
Rated flow speed (m/s)	2.5
Rated power (kW) at rated flow speed	500
Maximum flow speed (m/s)	3.5
Current speed (m/s) vs electric power output (kWe) data points	See below
Estimated date commercially available	2013-04
Estimated production cost per rated unit (EUR)	Unit size and volume dependent
Have environmental impact studies been performed	Yes
Technical publications	Many technical publications have been produced, a couple of these include: - J A Clarke, G Connor, A D Grant, C M Johnstone and S Ordonez-Sanchez 'Analysis of a Single Point Tensioned Mooring System for Station Keeping of a Contra-rotating Marine Current Turbine' Journal of Renewable Power Generation, IET, UK, December 2010. - J A Clarke, G Connor, A D Grant, C M Johnstone and S Ordonez-Sanchez 'Contrarotating Marine Turbines: Single Point Tethered Floating System – Stability and Performance' Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden, September 2009
Figures/photographs of device have been attached to reply	Yes
Could the device be combined with a suspension bridge fjord crossing / how?	Yes, from cables between the supports.

Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	Attaching the mooring lines to an overhanging bridge would allow the attachment points to be designed into the bridge structure, which saves time and money that is spent in a traditional installation attaching the mooring lines to the seabed. One disadvantage is the additional horizontal thrust load on the bridge structure from reacting the force absorbed by the device.
Could the device be combined with a floating bridge fjord crossing / how?	Yes, mooring lines could be attached between the pontoons or to the overhanging bridge assuming that there is enough clearance to turn around when the tides change direction.
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Yes, mooring lines could be attached between the pontoons so long as there is sufficient clearance between the pontoons. The effects of the pontoons on the flow characteristics around the device would have to be evaluated. These could have a positive effect by focusing and accelerating the flow, thus improving power capture. A disadvantage would again be the additional horizontal load on the supporting structure from the thrust load on the device.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Most definitely. Irrespective of depth, The mooring system would be secured to the tunnel in the same way as attaching the mooring line to the ocean floor
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	The big advantage is that it would be cheaper to install the device because an attachment point could be designed into the tunnel geometry, which saves time and money that is spent in a traditional installation attaching the mooring lines to the seabed. The disadvantage again would be the additional horizontal load on the supporting structure from the thrust load on the turbine.

Current Speed (m/s)	**Electrical Power Output (kWe)**
0.7	-
0.8	-
0.9	-
1	32
1.1	

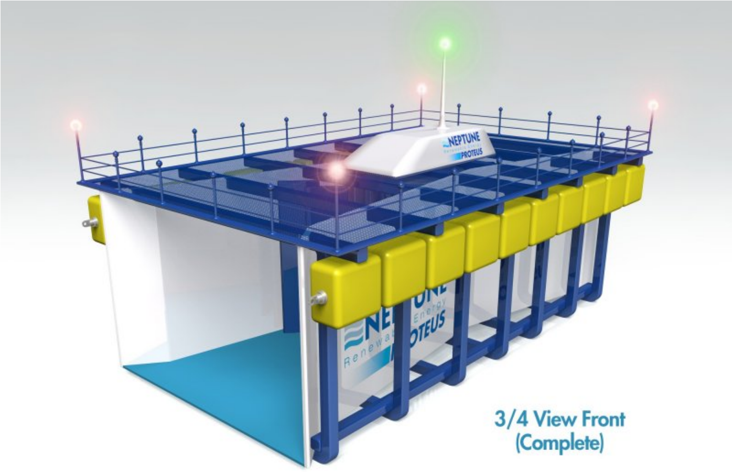
1.2	
1.3	
1.4	
1.5	106
1.6	
1.7	
1.8	
1.9	
2	252
2.1	
2.2	
2.3	
2.4	
2.5	500
2.6	
2.7	
2.8	
2.9	
3	600
3.1	
3.2	
3.3	
3.4	
3.5	600



Source - http://www.nautricity.com

Company	Neptune REnewable Energy Ltd
Country	UK
Web address	www.neptunerenewableenergy.com
Technology Name	
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	B
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	iii
Is power generated during ebb and flood flows	Yes
Features / Design principle	Each NP1200 has a three blades cross flow vertical axis rotor 10 D x 7.2m H driving gearbox and 400kW AC generator on a floating pontoon structure designed for estuarine sites
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Full scale prototype deployed on the North Bank of the Humber Estuary and grid connected
Next development steps	Production
Power train type	gearbox and generator
Dimensions	pontoon 11m x 11m turbine 10m (diam) x 7.2m (H)
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	72/device 360 / 2MW pod of 5
Weight of super structure (ton)	40T
Weight of power take off equipment (ton)	12T
Min installation depth (m)	none
Max installation depth (m)	none
Design lifetime (years)	20
Cut in speed (m/s)	0.5 m/s

Rated flow speed (m/s)	5 m/s
Rated power (kW) at rated flow speed	400 kW
Maximum flow speed (m/s)	tops out at 5 m/s
Current speed (m/s) vs electric power output (kWe) data points	Richards curve, asympotopic at 400kW at 5 m/s
Estimated date commercially available	2012
Estimated production cost per rated unit (EUR)	commercial in confidence
Have environmental impact studies been performed	yes and approved
Technical publications	Hardisty J (The University of Hull). The tidal stream power curve: A case study. A paper for Energy and Power Engineering v06
Figures/photographs of device have been attached to reply	see web site
Could the device be combined with a suspension bridge fjord crossing / how?	yes, moored between piles etc
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	
Could the device be combined with a floating bridge fjord crossing / how?	
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	
Could the device be combined with a submerged floating tunnel fjord crossing / how?	
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	



Source - www.neptunerenewableenergy.com

Company	Norwegian Ocean Power AS
Country	Norway
Web address	norwegianoceanpower.com
Technology Name	Pulsus turbine
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	E) Darieus turbine vertical axis
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	i) Seabed Mounted/Gravity Base (ii) pile mounted is fully conceivable)
Is power generated during ebb and flood flows	Yes
Features / Design principle	The Pulsus turbine is a very rugged design, it is designed for produsing power at lower flow speeds and it only has one moving part. The pulsus turbine is designed from a financial viability standpoint and has long maintenance & free operating intervalls - typical 10 years between service
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 6
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	The turbine has been in development for almost 10 years and we have carried out exstensive simulation and modeling,
Next development steps	currently we are building a 1:8 scale turbine for dynamic load testing that we will conduct this summer. A pilot powerplant with gridd connection is the next step after this summers test
Power train type	Direct drive generator
Dimensions	The turbines blades covers a sylindrical area, the cylinder diameter and hight varies after the intended maksimum power produktion at peek flow
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	Cross section area varies with powerplant size (600KW) 160 m2 (2,5MW) of 500m2
Weight of super structure (ton)	10-30 ton
Weight of power take off equipment	15-50 ton

(ton)	
Min installation depth (m)	17 - 34 meter
Max installation depth (m)	any dept if flow conditions are favorable
Design lifetime (years)	30
Cut in speed (m/s)	0.5
Rated flow speed (m/s)	2.6
Rated power (kW) at rated flow speed	600-2500
Maximum flow speed (m/s)	3.6
Current speed (m/s) vs electric power output (kWe) data points	
Estimated date commercially available	2014-05
Estimated production cost per rated unit (EUR)	
Have environmental impact studies been performed	NO
Technical publications	STUDY OF NORWEGIAN OCEAN POWER VERTICAL AXIS HELICAL BLADES HYDRO TURBINE Dr. Ion Paraschivoiu IOPARA Inc.
Figures/photographs of device have been attached to reply	full scale
Could the device be combined with a suspension bridge fjord crossing / how?	yes it could be suspended from the bridge
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	Suspending the turbine from the bridge would replace the normal seabed floor mooring. The turbine flow direction is omnidirectional. Simply suspending it into the water would be sufficient for operations. The mooring could be surface based, seafloore based or sideways. The turbine spins in the same direction regardless of flow direction and is very tolerant of turbulence.
Could the device be combined with a floating bridge fjord crossing / how?	Same as above
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Same as above
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes - the total available water depth only needs to be large enough to accomodate the turbine. (larger than turbine height)
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	An advantage is that devices positioned deeper will have positive effects on costs, since the environmental conditions are much more reliable. A disavantage is that current is often stronger at the surface.

Company	Oceanflow Energy Limited
Country	UK
Web address	www.OceanflowEnergy.com
Technology Name	Evopod
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	iii) Floating with flexible mooring (catenary or tension tether)
Is power generated during ebb and flood flows	Yes
Features / Design principle	Evopod consists of a patented low-motion semi-submerged floating platform which is modular in that it can be adapted to support multiple unshrouded turbine nacelles. The platform geometry that supports mono or twin turbines is tethered by a four point spread mooring. Each fixed pitch turbine is coupled through a step-up epicyclic gearbox to a variable speed induction or PM generator controlled by an inverter drive system to smooth the output power. The four line catenary mooring system allows the device to swing around with the tidal stream such that it is always facing into the flow. The mooring swivel incorporates a slipring for power export. The mooring lines are fixed to the seabed by pin pile or gravity anchors. This Evopod solution has been developed for open sea conditions where the flood and ebb tidal streams are not perfectly in parallel. Oceanflow's multi-turbine support platform for more sheltered estuarine conditions adopts the same semi-submerged platform design principles as Evopod but is moored fore and aft as the current direction reversals are constrained to 180 degrees by the geometry of the estuary or channel. The power train is the same as for Evopod only a full reversing pitch turbine is incorporated as the platform is moored on a fixed heading. The platform layout allows for access and removal of individual turbines for maintenance. The platform is moored fore and aft to the seabed by multi-line mooring system.

	Either catenary or tension tether mooring solutions can be employed. Tension tethers have the advantage of constraining platform motions but require larger capacity pile anchors to resist uplift forces.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	Turbine generator system: TRL 7 Evopod mono-turbine support platform: TRL 7 Multi-turbine support platform: TRL 3
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	1:40 scale models of the mono and twin turbine units have undergone performance, mooring and survivability tests at Newcastle and Strathclyde Universities flume and wave tanks between 2006 and 2009. A 1:10 scale fully functional device, including the full mooring system, has been in field testing in the tidal flows of Strangford Narrows, Northern Island, since 2008. The device is now grid-connected. The unit has also been used by Queen's University Belfast and Edinburgh University for turbine wake field analysis trials since 2009.
Next development steps	A 1:4 scale device is under construction for deployment in 2012 in Sanda Sound, South Kintyre, Scotland including grid connection. This unit has a rated output of 35kW and is termed our E35 unit. This is an open-ocean site, so the full effects of waves and storms will form part of the device testing phase. A full scale 1MW turbine is also being designed for deployment in a scaled up Evopod platform. This unit is expected to be under test at a site in Scottish waters by 2014.
Power train type	Turbine is coupled through a step-up epicyclic gearbox to a variable speed induction or PM generator controlled by an inverter drive.
Dimensions	Evopod E35, the 1:4 scale prototype, has a single nacelle and a turbine of 4.5m diameter. Its linear dimensions are length: 13m, beam: 4.5m, height: 8m, displacement: 13 tonnes. The 4-point spread mooring has anchor points on the seabed at each corner of an approximate 300m x 50m rectangle
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	Dimensions given below are for E35 unit and E1000 unit 20.3 / 201

Weight of super structure (ton)	10.4 / 65
Weight of power take off equipment (ton)	2.6 / 8
Min installation depth (m)	16 / 50
Max installation depth (m)	No limit
Design lifetime (years)	20
Cut in speed (m/s)	0.7
Rated flow speed (m/s)	2.3 / 3.6
Rated power (kW) at rated flow speed	35 / 1000
Maximum flow speed (m/s)	3.2 / 4.1
Current speed (m/s) vs electric power output (kWe) data points	See below
Estimated date commercially available	2012 (for 35kW unit) / 2014 (for 1MW unit)
Estimated production cost per rated unit (EUR)	Evopod estimated unit costs quoted below include cost of device, moorings, power export and control systems, grid connection and total system installation • €5000/kW installed (single unit rated at 35kW) • €2500/kW installed (multiple units each rated at 1MW for a 50MW farm) • €1200/kW installed (Costs of 1MW turbines and power generation nacelle only for integration into an available support structure for fjord crossing
Have environmental impact studies been performed	Yes An Assessment of Significance of Environmental Impact was carried out by an independent body for the Strangford Narrows deployment prior to obtaining approval to deploy from the Northern Ireland Environmental Agency. An Environmental Impact Assessment has been submitted to the Scottish regulatory authority (Marine Scotland) for the Sanda Sound deployment. Environmental baseline surveys have been carried out and post installation monitoring will be ongoing.
Technical publications	Development of Evopod Tidal Stream Turbine, G Mackie, RINA Marine Renewable Energy Conference, London November 2008.
Figures/photographs of device have been attached to reply	Embedded in this document
Could the device be combined with a suspension bridge fjord crossing / how?	No, as the normal height of a suspension bridge above the waterline would make it a health and safety risk to passing vessels if mooring lines attached to turbine units were deployed from the suspension bridge to the waterline. In addition the lateral loads transmitted by the not insignificant drag

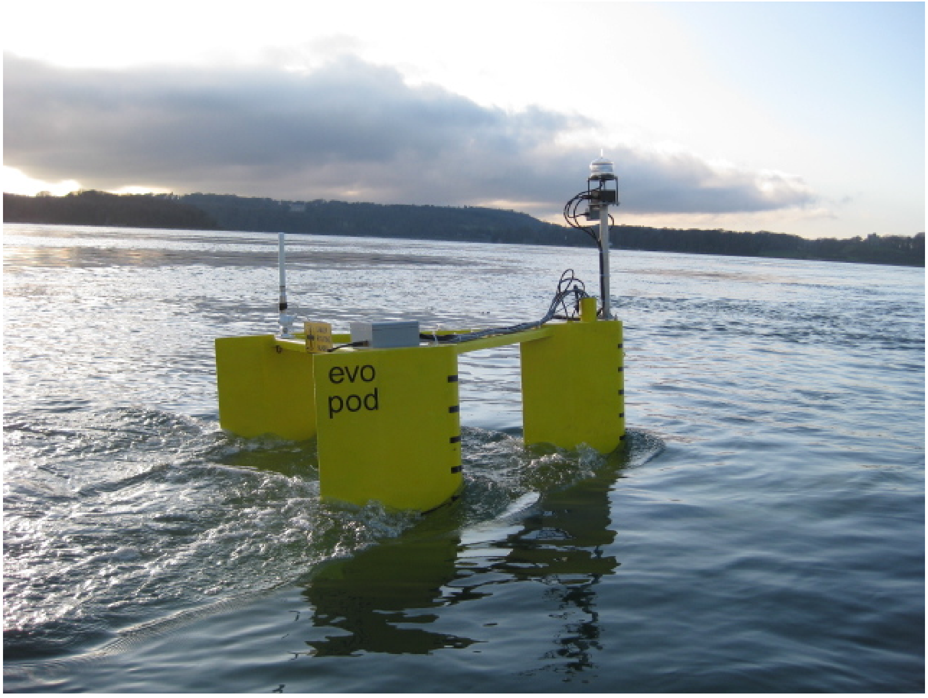
	forces of the turbine would change the design basis for a typical box girder suspension bridge by introducing excessive lateral loads.
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	See H&S risk referred to above. Also significant capital would need to be spent to reinforce an existing bridge, or upgrade plans for a proposed bridge, in order to cope with the drag force imposed on the structure by the Evopod platform.
Could the device be combined with a floating bridge fjord crossing / how?	Yes, this is a preferred solution. Oceanflow's multi-turbine support platform could be used as the support structure for a roadway. The semi-submerged turbine support platform with its streamline vertical struts would be an ideal structure for spanning a fjord. The platforms would be tension tethered to the seabed (see illustration). The turbines operate in channels between the vertical struts and can be removed for maintenance without disrupting the use of the roadway. The semi-submerged platform can be constructed in steel or reinforced concrete. It would be feasible to incorporate a section without turbines and with raised bridges to allow small vessels to pass through. The pictures below are for a floating river bridge crossing but could be adapted for a longer fjord crossing.

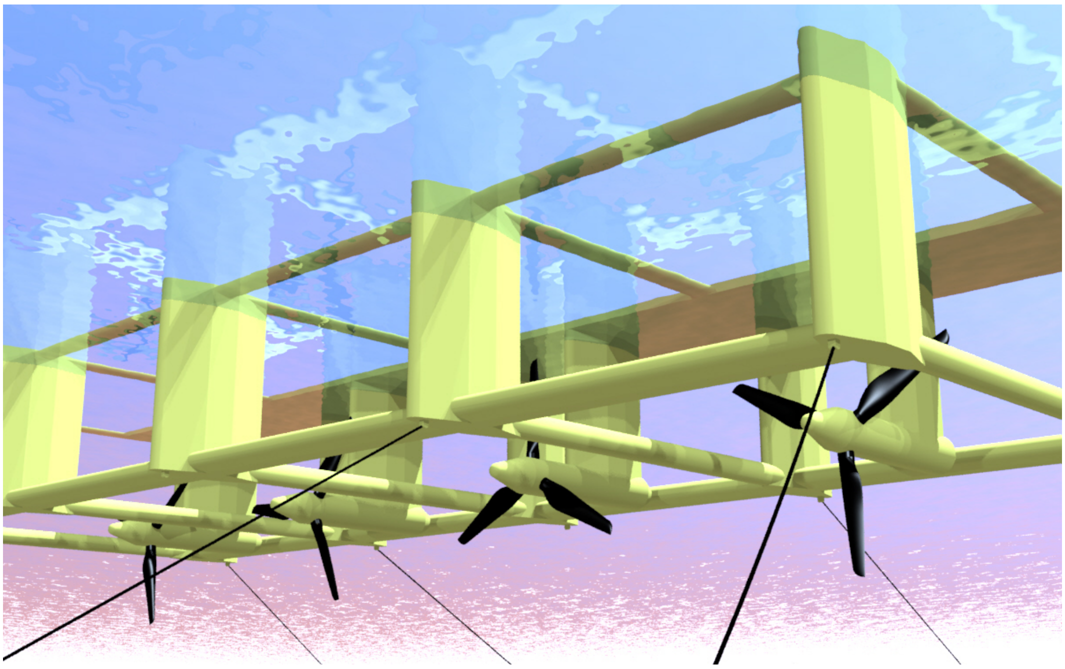
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Advantages: A floating bridge structure, being close to the waterline, is ideal for reacting the drag loads from a submerged tidal turbine. It is possible that flow speed could be higher in the areas between the bridge support structure, therefore enhancing the power density of the tidal stream at these locations. The blockage effect of multiple turbines could also create a small pressure head difference across the turbines which would increase energy recovery. This could make a floating bridge more attractive economically, because the power rating of each device could be higher for a given cross sectional area of water. The bridge structure simplifies machinery access and power export. Disadvantages: The turbines will increase the drag load on the floating bridge and will thus necessitate stronger moorings. However the facility will exist to park the turbine blades, which would significantly reduce turbine drag forces and could be used to limit mooring loadings under extreme environmental conditions. Yes, provided the design of the tunnel was such that the drag force would not compromise the safety of the tunnel.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes, provided the design of the tunnel was such that the drag force would not compromise the safety of the tunnel.
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	In an area where the tidal flow is sufficiently strong to make power generation attractive it will also be the case that the drag on a submerged tunnel will be very significant and will most likely rule out this option as a fjord crossing. It would be feasible to tie-off Evopod units to a submerged tunnel structure, effectively using the tunnel structure as an artificial seabed. The tunnel submergence would have to be sufficient so that it did not disturb the flow feeding into the tidal turbine.

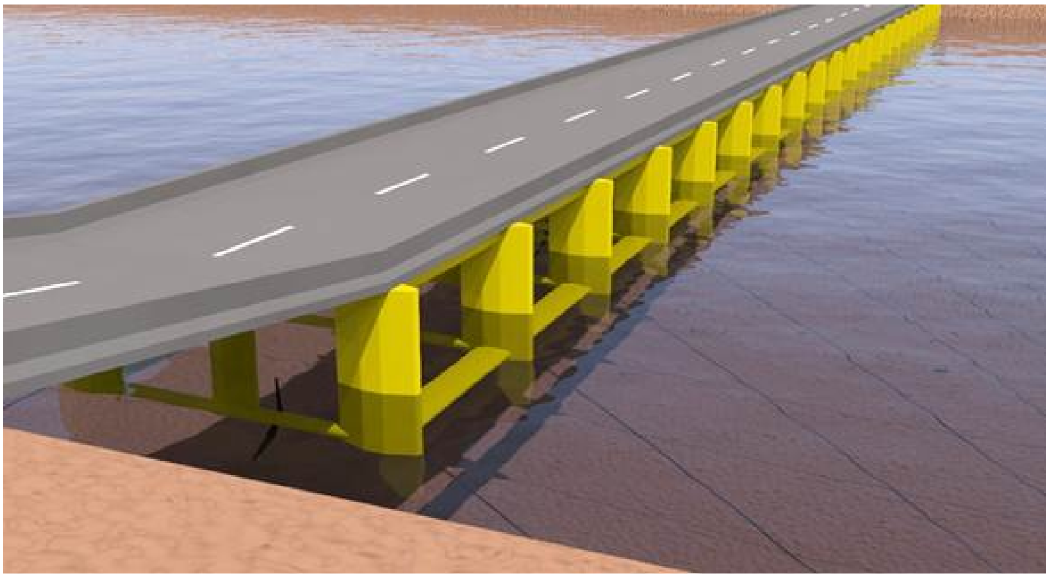
Current Speed (m/s)	**35kW unit rated for a flow speed of 2.3m/s**	**1000kW unit rated for a flow speed of 3.6m/s**

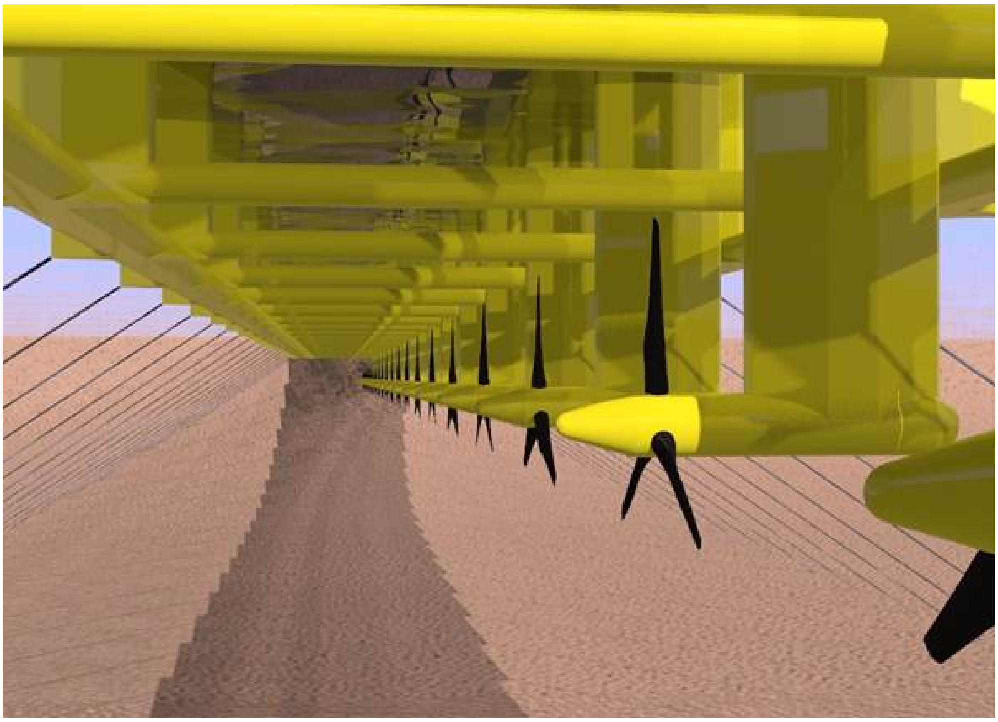
	Electric Power Output (kWe)	Electric Power Output (kWe)
0.6	0 (insufficient flow)	0 (insufficient flow)
0.7	1	12
0.8	1.5	18
0.9	2.1	26
1	2.9	36
1.1	3.8	48
1.2	4.9	62
1.3	6.3	79
1.4	7.8	99
1.5	10	122
1.6	12	148
1.7	14	177
1.8	17	210
1.9	20	247
2	23	289
2.1	26	334
2.2	30	384
2.3	35	439
2.4	39	499
2.5	45	564
2.6	50	634
2.7	32	710
2.8	36	792
2.9	40	880
3	44	974
3.1	49	1074
3.2	53	1182
3.3	0 (turbine shut down)	1296
3.4	0	1418
3.5	0	889
3.6	0	962
3.7	0	1044
3.8	0	1131
3.9	0	1222
4	0	1319
4.1	0	1420

4.2	0	0 (turbine shut down)





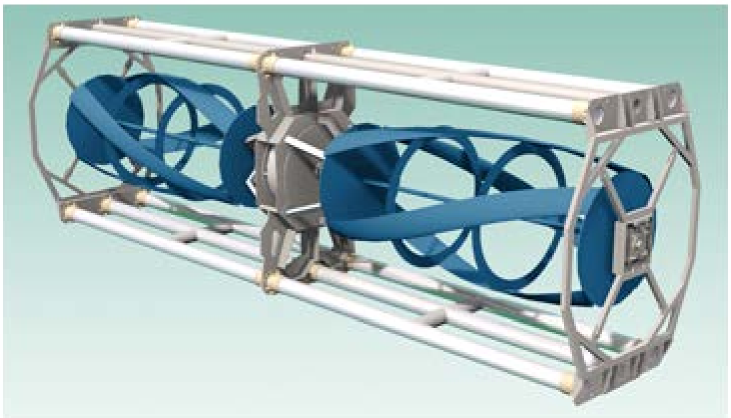




Company	Ocean Renewable Power Company
Country	United States
Web address	www.orpc.co
Technology Name	TidGen™, OCGen™
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	B (Turbine is a cross flow tubine, with the axis oriented horizontally)
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	(i)TidGen™ (iii) OCGen™
Is power generated during ebb and flood flows	Yes
Features / Design principle	ORPC's TidGen technology involves ORPC's patented TGU and a bottom support frame which provides structural support and holds it in place above the sea floor. The TGU is comprised of two proprietary advanced design crossflow turbines that drive a permanent magnet generator on a common drive shaft with equal efficiency on ebb and flood tides.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TidGen™- TRL 7/8, OCGen- TRL4
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	1:30 scale models (multiples) tested in University of Maine tow tank 1:10 scale model was tested during the ORPC Demonstration Project 1:3 scale model tested during ORPC Beta TGU Project A full scale unit is now being installed in Lubec, Maine, USA
Next development steps	Commercial deployment of TidGen™ Device in Eastport, Maine in March 2012.
Power train type	Direct drive generator
Dimensions	The overal length of the unit is 33m, height of 10m.

Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	
Weight of super structure (ton)	80
Weight of power take off equipment (ton)	34.5
Min installation depth (m)	None
Max installation depth (m)	45/
Design lifetime (years)	20
Cut in speed (m/s)	0.5
Rated flow speed (m/s)	3.0
Rated power (kW) at rated flow speed	180kW
Maximum flow speed (m/s)	4.0
Current speed (m/s) vs electric power output (kWe) data points	n/a publicly
Estimated date commercially available	2012
Estimated production cost per rated unit (EUR)	
Have environmental impact studies been performed	Yes
Technical publications	Viehman, H. (2011, November). Field evaluation of fish interactions with a commercial scale marine hydrokinetic device. Siegel, E. (2011, November). Using a forward looking acoustic doppler current profiler for turbine optimization and control. Maynard, M. (2011, November). The complexity of seabed investigations and foundation selection for high tidal energy environments: a case study from the ORPC Cobscook Bay TidGen™ Power System Project. Urbina, R. (2011, November). Modeling and validation of a cross flow turbine using free vortex model and modified dynamic stall model. Laoulache, R. (2011, November). Analysis of a vertical axis turbine using computational fluid dynamics at low and high solidities. Viehman, H., and G. Zydlewski, J. McCleave, and G. Staines (2012, January). Fishes and tidal power development in Cobscook Bay. Paper presented at 2012 Research Forum: Atlantic Salmon and Their Ecosystems, Bangor, ME.
Figures/photographs of device have	Yes

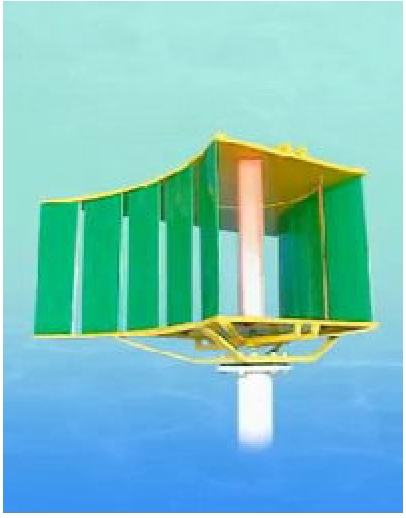
been attached to reply	
Could the device be combined with a suspension bridge fjord crossing / how?	Potentially in between the foundation piles
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	The design of the bridge is a permitted structure which may not allow for attachement of additional structures. The addition of turbine loads to a suspension bridge is novel. Dynamic loads on suspension bridges are potentially important. Resonance of the bridge structure is an issue. Turbuelence induced loads on the turbine may incite oscillating loads on the bridge structure. ORPC is unclear as to how this project will receive a permit and who will perform the structural calculations for the bridge
Could the device be combined with a floating bridge fjord crossing / how?	See above
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	See above
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes. The addition of a fixed bottom mounted structure is more analytical tractable than a floating or suspension bridge.
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	The main advantage is that it would be cheaper to install the device because an attachment point could be designed into the tunnel geometry, which saves time and money that is spent in a traditional installation attaching the mooring lines to the seabed. The disadvantage again would be the additional horizontal load on the supporting structure caused by reacting the force absorbed by the device.



Source - www.orpc.co

Company	Tidal Energy Pty Ltd
Country	AUSTRALIA
Web address	http://tidalenergy.com.au/
Technology Name	Davidson-Hill Venturi Turbine
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	Cross-Axis Venturi Turbine
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	Seabed Pile Floating Site dependent
Is power generated during ebb and flood flows	Yes
Features / Design principle	One (1) shrouded turbine with a single rotor efficiency of 60% water to wire conversion - world record holder. Swivel base allows generation on flood/ebb/river or ocean currents.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	Commencing mass production
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Proof of Concept - passed Small prototype - passed Commercial scale up - passed Canada "BETA" tested - passed All reports available upon request.
Next development steps	Development complete - mass production phase set to commence 2012.
Power train type	Shaft/rim or direct drive
Dimensions	1.5 x 1.5 m rotor (up to 120kW*) 2.4 x 2.4 m rotor (up to 300kW*) 5 x 5 m rotor (up to 1.3 MW*) 7 x 7 m rotor (up to 2.7 MW*) 10 x 10 m rotor (up to 5.5 MW*) * 6m/s velocity
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for	As above

an unshrouded turbine Plan form area for a vertical axis turbine	
Weight of super structure (ton)	varies
Weight of power take off equipment (ton)	varies
Min installation depth (m)	2 x rotor diameter
Max installation depth (m)	>100m
Design lifetime (years)	25 years
Cut in speed (m/s)	immediate start from standstill
Rated flow speed (m/s)	up to 12 m/s
Rated power (kW) at rated flow speed	as above
Maximum flow speed (m/s)	up to 12 m/s
Current speed (m/s) vs electric power output (kWe) data points	http://tidalenergy.com.au/faq.html
Estimated date commercially available	2012
Estimated production cost per rated unit (EUR)	from AU$125,000 (100kW)
Have environmental impact studies been performed	Supported by QLD Australia EPA
Technical publications	Available upon request
Figures/photographs of device have been attached to reply	http://tidalenergy.com.au/faq.html
Could the device be combined with a suspension bridge fjord crossing / how?	Possibly
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	
Could the device be combined with a floating bridge fjord crossing / how?	Cantilever or cable to the shore
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Pure speculation
Could the device be combined with a submerged floating tunnel fjord crossing / how?	As above
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	Unknown



Source - http://tidalenergy.com.au/

Company	Tidal Generation Limited
Country	UK
Web address	www.tidalgeneration.co.uk
Technology Name	TGL 1MW Turbine
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A)
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	i)
Is power generated during ebb and flood flows	Yes
Features / Design principle	Upstream rotor, three variable pitch blades, yaws to face the tide, outputs grid compliant power. Buoyant nacelle for rapid low cost deployment. Lightweight tripod foundation pinned to seabed
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL6
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	500kW concept demonstrator installed at EMEC (European Marine Energy Centre) in September 2010 and exported 215 MWh to the grid up to March 2012. Achieved extended periods (up to 4 weeks) of continuous automated and remote controlled operation.
Next development steps	1MWe device is under construction at present and due for deployment in Q3 2012. It will then undergo a 2 year test programme gathering device and environmental impact data. This device will achieve TRL7. Beyond this TGL are negotiating to install a small demonstration array of 5 or more 1MWe devices and these will be under pre-commercial terms and deliver TRL8.
Power train type	Step-up gearbox and induction generator
Dimensions	Turbine nacelle is 20.5m long, 3.5m diameter, 5.3m high (max. dimension) with 18.2m blade swept diameter. Structure is 16m high.
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine	254m2

Plan form area for a vertical axis turbine	
Weight of super structure (ton)	100 approx.
Weight of power take off equipment (ton)	150
Min installation depth (m)	40
Max installation depth (m)	80
Design lifetime (years)	30
Cut in speed (m/s)	1.0
Rated flow speed (m/s)	2.7
Rated power (kW) at rated flow speed	1,000
Maximum flow speed (m/s)	5.0 m/s (site and wave dependent, may be lower than this)
Current speed (m/s) vs electric power output (kWe) data points	
Estimated date commercially available	2016
Estimated production cost per rated unit (EUR)	N/A
Have environmental impact studies been performed	In progress at EMEC
Technical publications	N/A
Figures/photographs of device have been attached to reply	Refer to TGL website
Could the device be combined with a suspension bridge fjord crossing / how?	The current TGL device is not suited to this requirement.
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	The TGL device is designed to be mounted on a rigid structure attached to the sea bed. It has a deployment and retrieval method based on a buoyant nacelle which again assumes a structure that is underneath the turbine. To allow the turbine to be suspended from a bridge would require considerable modification. In fact there may well be other technical solutions that would make the turbine lower cost as the turbine could be “hung” under a rigid support from a suspension bridge.
Could the device be combined with a floating bridge fjord crossing / how?	The current TGL device is not suited to this requirement.
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	The TGL device is designed to be mounted on a rigid structure attached to the sea bed. It has a deployment and retrieval method based on a buoyant nacelle which again assumes a structure that is underneath the turbine. To allow the turbine to be suspended from a bridge would require considerable modification. In fact there may well be other technical solutions that would make the turbine

	lower cost as the turbine could be "hung" under a rigid support connected to a floating bridge.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	The current TGL device could be adapted to this requirement.
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	The TGL device is designed to be mounted on a rigid structure attached to the sea bed. It has a deployment and retrieval method based on a buoyant nacelle which again assumes a structure that is underneath the turbine. A submerged floating tunnel could be treated as the "sea bed" and a structure could be designed to which the TGL turbine could be attached. The turbine would need to be above the bridge rather than below.

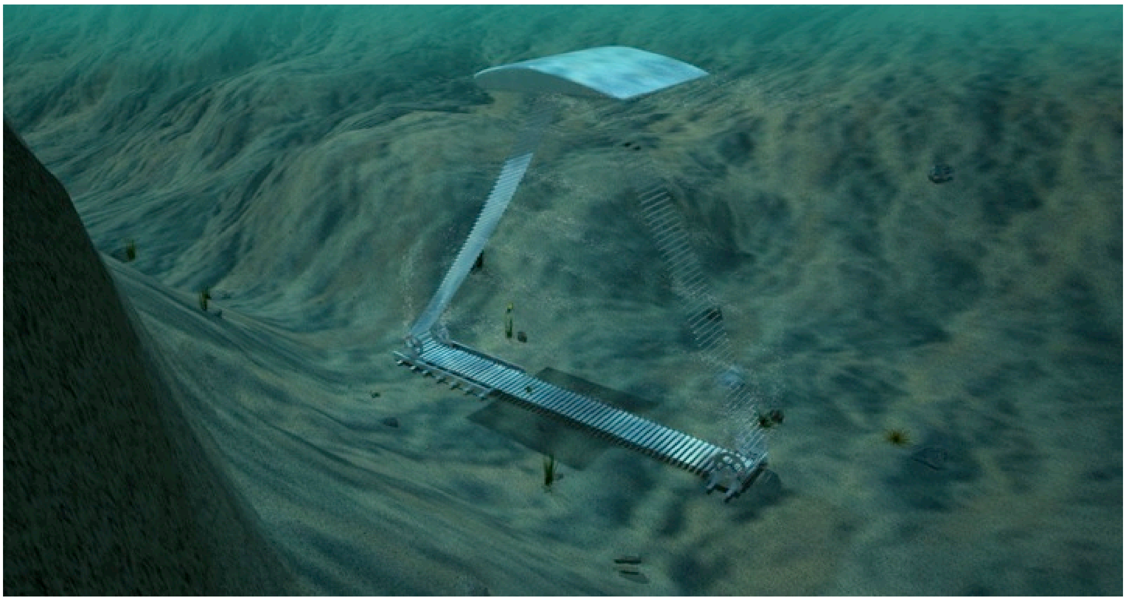
Source - www.tidalgeneration.co.uk

Company	Tidal Sails AS
Country	Norway
Web address	www.tidalsails.com
Technology Name	TidalSails
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	E
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	iii
Is power generated during ebb and flood flows	
Features / Design principle	Linearly moving sail profiles travelling a triangular track with several hundred meter legs, attached to a rope belt rotating large sheaves driving generators.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Several prototypes tested in Haugesund since 2007, Balder Demonstration via Eurostars project fall of 2011, Full skale engineering ongoing for deployment primo 2013
Next development steps	Tidal Sails Ocean Energy Test Center, Skjoldastraumen in Tysvær, up to 3m/s 30 minutes east of Haugesund
Power train type	Direct PMG 3-10MW
Dimensions	Up to 500 meter legs, up to 500 sails, 10 x1m
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	Up to 10 000
Weight of super structure (ton)	Up to 200
Weight of power take off equipment (ton)	Up to 100
Min installation depth (m)	10 (Floating version)

Max installation depth (m)	Unlimited, Max for Tidal Sails Vertical: 500m
Design lifetime (years)	20 plus
Cut in speed (m/s)	1
Rated flow speed (m/s)	2
Rated power (kW) at rated flow speed	10000
Maximum flow speed (m/s)	16, Of course with much smaller sails and shorter legs!!! 1
Current speed (m/s) vs electric power output (kWe) data points	
Estimated date commercially available	Late fall of 2013
Estimated production cost per rated unit (EUR)	M6-10€
Have environmental impact studies been performed	Yes
Technical publications	DnV
Figures/photographs of device have been attached to reply	
Could the device be combined with a suspension bridge fjord crossing / how?	Yes, the standing configuration shown in the figure could be mounted to a floating bridge fjord crossing
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	Nice view with LED lights on each sail from the deep;-)
Could the device be combined with a floating bridge fjord crossing / how?	Yes, the standing configuration shown in the figure could be mounted to a floating bridge fjord crossing
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	?
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes, the standing configuration shown in the figure could be mounted to a floating bridge fjord crossing
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	?

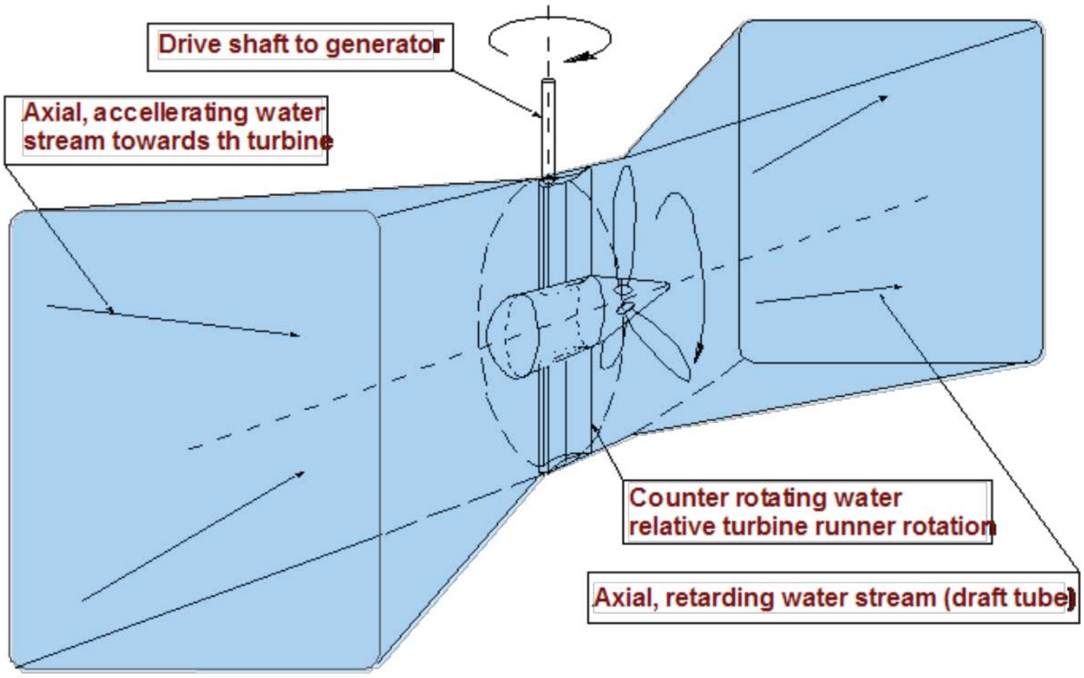
Current Speed (m/s)	**Electric Power Output (kWe)**
0.7	
0.8	
0.9	
1	
1.1	1000
1.2	
1.3	5000
1.4	

1.5	8000
1.6	
1.7	10000
1.8	
1.9	
2	10000
2.1	
2.2	
2.3	
2.4	
2.5	
2.6	
2.7	
2.8	
2.9	
3	
3.1	
3.2	
3.3	
3.4	
3.5	



Company	TideTec AS
Country	Norway
Web address	wwe.tidetec.no
Technology Name	TideTec energibru konsept
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	D) Turnable Kaplan-type turbine patented by TideTec
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	Turbine mounted in bridge structure that are seabed mounted, but turbines may also be mounted in floating bridge.
Is power generated during ebb and flood flows	Yes
Features / Design principle	Turnable +/- 180 degrees around the vertical axis. According to University of Liverpool report: This provides up to 56% added power production compared to traditional single-direction Kaplan turbines. Pre-fabricated seabed mounted concrete sections makes the foundation for bridge and turbines and focuses the tidal currents into the turbines. An option for wave energy on the same turbines is also patented. See: http://tidetec.com/?page_id=180
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL3- 4
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Planned TRL4-5 project for testing and proof of concept in Narvik. See attached note "Energibru Narvik"
Next development steps	Testing scale model in laboratory. Modelling and calculating of costs etc. Se attached note: "Energibru Narvik"
Power train type	Mechanical gear to high speed standard generator
Dimensions	Turbine diameter adjusted for locations but normal diameter beetween 5-10 meters
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis	Depends on the locations. See example Narvik

turbine	
Weight of super structure (ton)	
Weight of power take off equipment (ton)	
Min installation depth (m)	approx. 8-10 m
Max installation depth (m)	Seabed mounted bridge: Not yet decided. Floating bridge: unlimited.
Design lifetime (years)	
Cut in speed (m/s)	
Rated flow speed (m/s)	
Rated power (kW) at rated flow speed	
Maximum flow speed (m/s)	
Current speed (m/s) vs electric power output (kWe) data points	
Estimated date commercially available	
Estimated production cost per rated unit (EUR)	
Have environmental impact studies been performed	yes
Technical publications	see attached "høringsuttalelse fra Tidetec…"
Figures/photographs of device have been attached to reply	see attached "høringsuttalelse fra Tidetec…"
Could the device be combined with a suspension bridge fjord crossing / how?	no
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	
Could the device be combined with a floating bridge fjord crossing / how?	yes
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	This is an interesting possibility, but much testing and proofing remains. Especially interesting to combine TideTec turbines with waves.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	no
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	



Visualization of the TT turbine dynamics

Company	Tocardo International BV - Hydropower from Holland
Country	Netherlands
Web address	www.tocardo.com
Technology Name	Tocardo T100, Tocardo T200
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	Free flow, horizontal axes, direct drive generator, fixed pitch (bi-directional) blades.
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	Multiple ways: - Floating (flexible or rigid moored platform) - Bottom mounted (gravity based, pile based) - Retro fitted to existing structures (bridges, barrages, dames, tunnels etc.)
Is power generated during ebb and flood flows	The turbines can be equipped with (patented) bi-directional blades which will automatically (without the use of a pitching mechanism) flip when the flow reverses.
Features / Design principle	Tocardo offers turbines with a rated power of 50, 100, 200 and 500 kW. The 100 and 200 kW turbines are commercially available. The focus of the design is on kWh. This means the turbines are built to be robust and thus need very little maintenance. The bi-directional blade enables the turbines to operate in bi-directional flows without the need of vulnerable pitching mechanisms. The turbines are designed to be attached to any kind of structure, ranging from bridges, barrages, floating platforms to bottom mounted.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	Commercially available
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A Tocardo T100 has been installed in Den Oever, the Netherlands since 2008 and has been grid connected (and delivering power) since then. This is a demo project which proofs the technology. The T200 turbine is an up-scaled copy of the T100 using the same technologies.
Next development steps	Tocardo started to roll out commercial activities and is now involved in setting up projects in: - UK - Scotland - Canada - Japan - USA - Korea

Power train type	Direct drive generator
Dimensions	**T100** Turbine: - Rotor diameter: 6.4 m - Total length of turbine(incl rotor): 4.38 m - Nacelle diameter: 1.03 m Foundation: - Foundation size depends on the foundation type, location and the number of turbines attached. Power cabinet: - 2.0 x 0.8 x 2.3 m (WxDxH) **T200** Turbine: - Rotor diameter: 9.2 m - Total length of turbine(incl rotor): 6 m - Nacelle diameter 1.40 m Foundation: - Foundation size depends on the foundation type, location and the number of turbines attached. Power cabinet: - 2.0 x 1.0 x 2.3 m (WxDxH)
Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	T100 - 32.2 m2 T200 - 66.5 m2
Weight of super structure (ton)	Total weight incl rotor: T100 - 4925 kg T200 - 11400 kg
Weight of power take off equipment (ton)	600 kg
Min installation depth (m)	Minimum nacelle depth: T100 - 3.7 m T200 - 5.1 m
Max installation depth (m)	Maximum nacelle depth: 25 m
Design lifetime (years)	20
Cut in speed (m/s)	0.4 m/s
Rated flow speed (m/s)	2 - 4 m/s (adjustable with blade size)
Rated power (kW) at rated flow speed	T100 - 43 kW T200 - 87 kW
Maximum flow speed (m/s)	4 m/s (survival speed)
Current speed (m/s) vs electric power output (kWe) data points	Please see Appendix for a power curve and rated power table.

Estimated date commercially available	T100 and T200 are commercially available. Delivery time 6-7 months.
Estimated production cost per rated unit (EUR)	T100 - € 242.100 T200 - € 424.600 Single turbine, incl rotor and control/electro cabinet, excl foundation/installation cost, FOB Port of Rotterdam.
Have environmental impact studies been performed	A preliminary fish impact study has been done in Den Oever. No deaths or injuries were recorded caused by the turbine. Tocardo is preparing a project in the Oosterschelde storm barrage in the south of the Netherlands. All (environmental) permits for this project have been approved by the responsible authorities. An impact study was done as a basis for the environmental permits.
Technical publications	No technical publications, as Tocardo is a commercial company, not a research company.
Figures/photographs of device have been attached to reply	Yes, see rest of the document
Could the device be combined with a suspension bridge fjord crossing / how?	Yes. Turbines van be directly attached to the bridge pillars or a platform can be attached to the bridge. Tocardo works together with partners for foundation and installation solutions. Tocardo's partners are: - Rambol - RES - SMT Strukton
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	Disadvantage: - Restriction in numbers when attached to pilars (if pilars are in the water) - Extra load on bridge pilars or bridge deck. As the bridge pilars are the strongest parts, the extra load is neglectible. Advantages: - Low cost when attached to pilars (foundation is allready there) - Connecting to the pilars or the deck can be included in the bridge design, reducing costs - No extra space is used for a floating platform when attached to the pilars - Easy and cheap connection to the grid using bridge structure
Could the device be combined with a floating bridge fjord crossing / how?	Yes. Turbines can be (retro) fitted to a floating bridge. Either by directly attaching them to the parts of the bridge that are submerged or by mooring a platform to the bridge. Tocardo's partner, SMT (Sustainable Marine Technologies), are experts in engineering floating solutions.

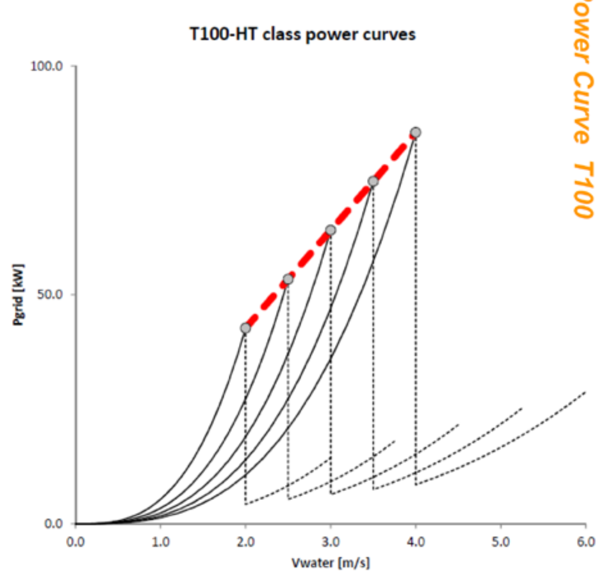
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Disadvantage: - When using a special platform this is more expensive - Additional load on the bridge Advantage: - The floating parts of the bridge can be used as foundation (cost reduction) - The grid connection can be realized using the bridge, cost reduction No extra space is used when attaching to the bridge
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes, depending on the depth (max 25 m). Turbines can be directly attached to the tunnel or attached with mooring lines to a floating platform.
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	Disadvantage: - Extra load on the tunnel - Restrction of depth for the tunnel Advantage: - When directly attached to the tunnel no extra foundation is necessary - Grid connectioncan be realized using the tunnel The energy generated can be used to supply power to the tunnel

TOCARDO BV INTERNATIONAL

Appendix A: Power Curve T100

T100-HT class power curves

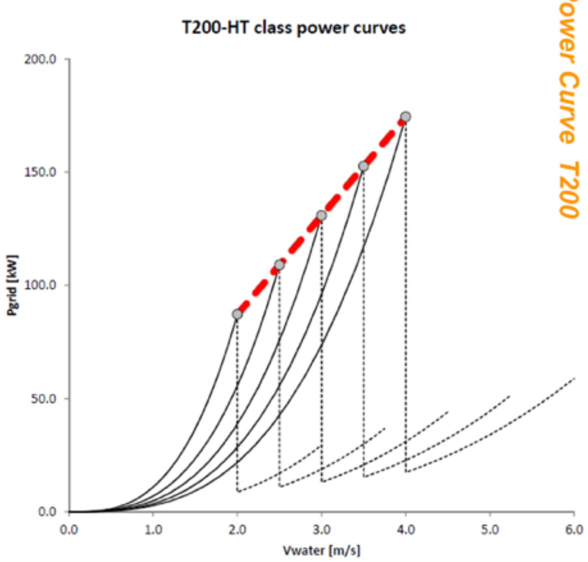
Range	HT2.0 V [m s-1]	HT2.0 Pgrid [kW]	HT2.5 V [m s-1]	HT2.5 Pgrid [kW]	HT3.0 V [m s-1]	HT3.0 Pgrid [kW]	HT3.5 V [m s-1]	HT3.5 Pgrid [kW]	HT4.0 V [m s-1]	HT4.0 Pgrid [kW]
Nominal power range	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.1	0.0	0.1	0.0	0.2	0.0	0.2	0.0	0.2	0.0
	0.2	0.0	0.3	0.1	0.3	0.1	0.4	0.1	0.4	0.1
	0.3	0.1	0.4	0.2	0.5	0.2	0.5	0.3	0.6	0.3
	0.4	0.3	0.5	0.4	0.6	0.5	0.7	0.6	0.8	0.7
	0.5	0.7	0.6	0.8	0.8	1.0	0.9	1.2	1.0	1.3
	0.6	1.2	0.8	1.4	0.9	1.7	1.1	2.0	1.2	2.3
	0.7	1.8	0.9	2.3	1.1	2.7	1.2	3.2	1.4	3.7
	0.8	2.7	1.0	3.4	1.2	4.1	1.4	4.8	1.6	5.5
	0.9	3.9	1.1	4.9	1.4	5.8	1.6	6.8	1.8	7.8
	1.0	5.3	1.3	6.7	1.5	8.0	1.8	9.4	2.0	10.7
	1.1	7.1	1.4	8.9	1.7	10.7	1.9	12.4	2.2	14.2
	1.2	9.2	1.5	11.5	1.8	13.9	2.1	16.2	2.4	18.5
	1.3	11.7	1.6	14.7	2.0	17.6	2.3	20.5	2.6	23.5
	1.4	14.7	1.8	18.3	2.1	22.0	2.5	25.7	2.8	29.3
	1.5	18.0	1.9	22.5	2.3	27.1	2.6	31.6	3.0	36.1
	1.6	21.9	2.0	27.4	2.4	32.8	2.8	38.3	3.2	43.8
	1.7	26.3	2.1	32.8	2.6	39.4	3.0	45.9	3.4	52.5
	1.8	31.2	2.3	39.0	2.7	46.7	3.2	54.5	3.6	62.3
	1.9	36.7	2.4	45.8	2.9	55.0	3.3	64.1	3.8	73.3
	2.0	42.8	2.5	53.4	3.0	64.1	3.5	74.8	4.0	85.5
Stall power range	2.0	4.3	2.5	5.3	3.0	6.4	3.5	7.5	4.0	8.6
	2.1	4.9	2.6	6.2	3.2	7.4	3.7	8.7	4.2	9.9
	2.2	5.7	2.8	7.1	3.3	8.5	3.9	10.0	4.4	11.4
	2.3	6.5	2.9	8.1	3.5	9.8	4.0	11.4	4.6	13.0
	2.4	7.4	3.0	9.2	3.6	11.1	4.2	12.9	4.8	14.8
	2.5	8.4	3.1	10.4	3.8	12.5	4.4	14.6	5.0	16.7
	2.6	9.4	3.3	11.7	3.9	14.1	4.6	16.4	5.2	18.8
	2.7	10.5	3.4	13.1	4.1	15.8	4.7	18.4	5.4	21.0
	2.8	11.7	3.5	14.7	4.2	17.6	4.9	20.5	5.6	23.5
	2.9	13.0	3.6	16.3	4.4	19.6	5.1	22.8	5.8	26.1
	3.0	14.4	3.8	18.0	4.5	21.6	5.3	25.3	6.0	28.9



Appendix B: Power Curve T200

T200-HT class power curves

	HT2.0 V [m s-1]	HT2.0 Pgrid [kW]	HT2.5 V [m s-1]	HT2.5 Pgrid [kW]	HT3.0 V [m s-1]	HT3.0 Pgrid [kW]	HT3.5 V [m s-1]	HT3.5 Pgrid [kW]	HT4.0 V [m s-1]	HT4.0 Pgrid [kW]
Nominal power range	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.1	0.0	0.1	0.0	0.2	0.0	0.2	0.0	0.2	0.0
	0.2	0.1	0.3	0.1	0.3	0.1	0.4	0.2	0.4	0.2
	0.3	0.3	0.4	0.4	0.5	0.4	0.5	0.5	0.6	0.6
	0.4	0.7	0.5	0.9	0.6	1.0	0.7	1.2	0.8	1.4
	0.5	1.4	0.6	1.7	0.8	2.0	0.9	2.4	1.0	2.7
	0.6	2.4	0.8	2.9	0.9	3.5	1.1	4.1	1.2	4.7
	0.7	3.7	0.9	4.7	1.1	5.6	1.2	6.5	1.4	7.5
	0.8	5.6	1.0	7.0	1.2	8.4	1.4	9.8	1.6	11.2
	0.9	8.0	1.1	9.9	1.4	11.9	1.6	13.9	1.8	15.9
	1.0	10.9	1.3	13.6	1.5	16.4	1.8	19.1	2.0	21.8
	1.1	14.5	1.4	18.1	1.7	21.8	1.9	25.4	2.2	29.0
	1.2	18.8	1.5	23.6	1.8	28.3	2.1	33.0	2.4	37.7
	1.3	24.0	1.6	30.0	2.0	35.9	2.3	41.9	2.6	47.9
	1.4	29.9	1.8	37.4	2.1	44.9	2.5	52.4	2.8	59.9
	1.5	36.8	1.9	46.0	2.3	55.2	2.6	64.4	3.0	73.6
	1.6	44.7	2.0	55.8	2.4	67.0	2.8	78.2	3.2	89.3
	1.7	53.6	2.1	67.0	2.6	80.4	3.0	93.8	3.4	107.2
	1.8	63.6	2.3	79.5	2.7	95.4	3.2	111.3	3.6	127.2
	1.9	74.8	2.4	93.5	2.9	112.2	3.3	130.9	3.8	149.6
	2.0	87.2	2.5	109.1	3.0	130.9	3.5	152.7	4.0	174.5
Stall power range	*2.0*	*8.7*	*2.5*	*10.9*	*3.0*	*13.1*	*3.5*	*15.3*	*4.0*	*17.4*
	2.1	*10.1*	*2.6*	*12.6*	*3.2*	*15.2*	*3.7*	*17.7*	*4.2*	*20.2*
	2.2	*11.6*	*2.8*	*14.5*	*3.3*	*17.4*	*3.9*	*20.3*	*4.4*	*23.2*
	2.3	*13.3*	*2.9*	*16.6*	*3.5*	*19.9*	*4.0*	*23.2*	*4.6*	*26.5*
	2.4	*15.1*	*3.0*	*18.8*	*3.6*	*22.6*	*4.2*	*26.4*	*4.8*	*30.2*
	2.5	*17.0*	*3.1*	*21.3*	*3.8*	*25.6*	*4.4*	*29.8*	*5.0*	*34.1*
	2.6	*19.2*	*3.3*	*24.0*	*3.9*	*28.8*	*4.6*	*33.5*	*5.2*	*38.3*
	2.7	*21.5*	*3.4*	*26.8*	*4.1*	*32.2*	*4.7*	*37.6*	*5.4*	*42.9*
	2.8	*23.9*	*3.5*	*29.9*	*4.2*	*35.9*	*4.9*	*41.9*	*5.6*	*47.9*
	2.9	*26.6*	*3.6*	*33.2*	*4.4*	*39.9*	*5.1*	*46.5*	*5.8*	*53.2*
	3.0	*29.4*	*3.8*	*36.8*	*4.5*	*44.2*	*5.3*	*51.5*	*6.0*	*58.9*



Appendix C: T100 product information

Tocardo T100

TOCARDO BV INTERNATIONAL

"hydropower from Holland"

The Tocardo T100 system offers a complete water to grid solution for open flowing water like rivers, channels and tidal currents. The T100 has a rated output of 100 kW and is designed to operate at water speeds starting at 2 m/s (4 kts). The system is designed to minimize maintenance and maximize power output over its 20 year lifetime.

The turbine is equipped with a robust blade with a diameter range of 3.2m - 6.4m depending on the site requirements. Thanks to its small size, T100 is ideal for river applications, post-hydro installation and retro-fitting in on bridges and in (tidal) barrages.

Typical energy yield

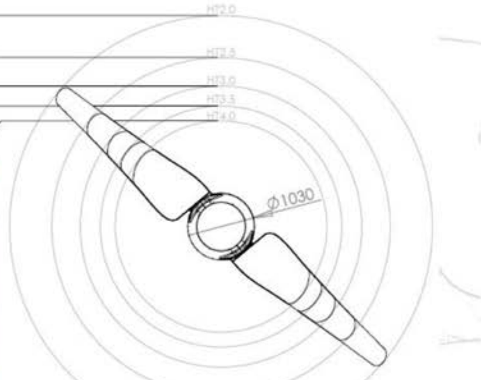
Velocity [m/s]	2.00	2.50	3.00	3.50	4.00
Power [kW]	43	53	64	75	86
Site type	Typical annual energy yield [MWh / year]				
Tidal	94	118	141	165	188
River	214	267	321	374	428

Why Tocardo?

- Reliable and robust technology
- 100% predictable energy output
- Competitive renewable KWh cost
- Scalable site solutions
- Low maintenance cost
- Long operating life time
- Short manufacturing lead times
- Easy to install

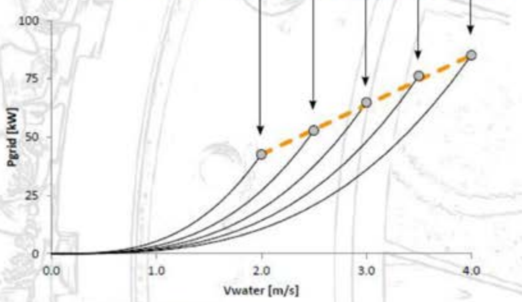
Tocardo International BV - Sluiskolkkade 2, 1779GP, Den Oever, The Netherlands (head office)
P: +31-226-42 34 11 - E: sales@tocardo.com - W: www.tocardo.com
-- new office address!! (from nov 1st 2011) --

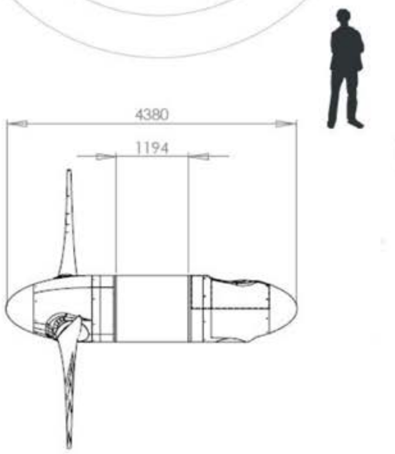
Tocardo T100



Operating data

Rated water velocity	[m/s]	2.00	2.50	3.00	3.50	4.00
Blade D	[m]	6.4	5.1	4.3	3.7	3.2
Swept area	[m²]	32.2	20.4	14.5	10.8	8.0
Rated grid power	[kW]	43	53	64	75	86
Rated revs	[rpm]	31	39	47	54	63
Cut-in water speed	[m/s]	0.4	0.5	0.6	0.7	0.8
Cut-out water speed	[m/s]	2.6	3.8	4.5	5.3	6.0
Survival water speed	[m/s]	4.0	5.0	6.0	7.0	8.0





Nacelle dimensions

Diameter	[m]	1.03				
Length (nose-tail)	[m]	4.38				
Total weight (dry)	[kg]	4925	4890	4850	4815	4785
Foundation mount		Bolted flange type				

Power cabinet dimensions

Space required	WxDxH	2.0 x 0.8 x 2.3
Weight	[kg]	600
Environmental conditions		Protected environment, non-condensing, properly vented

Other infomation

General

Number of blades	2
Power regulation	Fixed pitch, variable speed, stall regulated
Directionality	Uni- & bi-directional
Power curve up to Vrated	3rd order, constant lambda
Power curve above Vrated	3rd order, stall regulated (overdrive mode)

Generator

Type	14-pole, permanent magnet, direct drive, variable speed
Model	Tocardo DD700HT

Power conversion

Converter type	Solid state AC-DC-AC conversion, IGBT drive
Feed-in voltage	400V (customisable)
Feed-in frequency	50 / 60

Specifications and energy yields are for information purposes only and do not represent any warranty or promise; data is subject to change without prior notice.

2

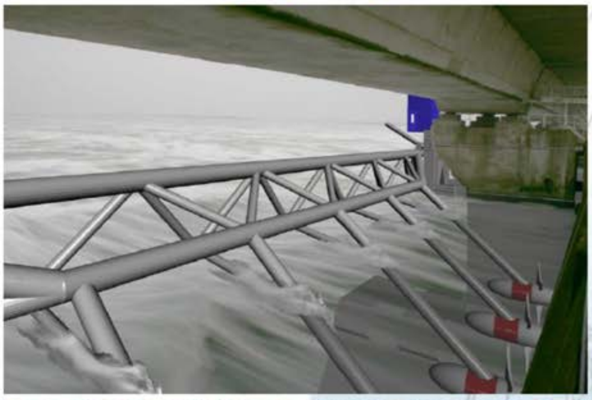
version T100-DD700HT v1.2a

Appendix D: T200 product information

Tocardo T200

TOCARDO BV INTERNATIONAL

"hydropower from Holland"



The Tocardo T200 system offers a complete water to grid solution for open flowing water like rivers, estuaries and (ocean) tidal currents. The T200 has a rated output of 200 kW and is designed to operate at water speeds starting at 1.5 m/s (3 knots).

The system is designed to minimize maintenance and maximize power output over its 20 year lifetime. The turbine is equipped with a robust blade with a diameter range of 4.6m – 9.2m depending on the site requirements. The T200 is ideal for deep river applications, retro-fitting on bridges and in (tidal) barrages, estuaries and deployment in the ocean tidal currents.

Typical energy yield

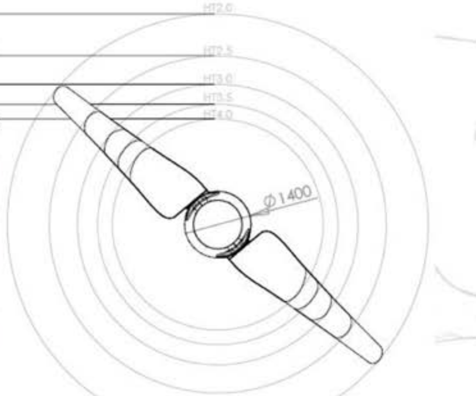
Velocity [m/s]	2.00	2.50	3.00	3.50	4.00
Power [kW]	87	109	131	153	174
Site type	Typical annual energy yield [MWh / year]				
Tidal	192	240	288	336	384
River	436	545	654	763	872

Why Tocardo?

- Reliable and robust technology
- 100% predictable energy output
- Competitive renewable KWh cost
- Scalable site solutions
- Low maintenance cost
- Long operating life time
- Short manufacturing lead times
- Easy to install

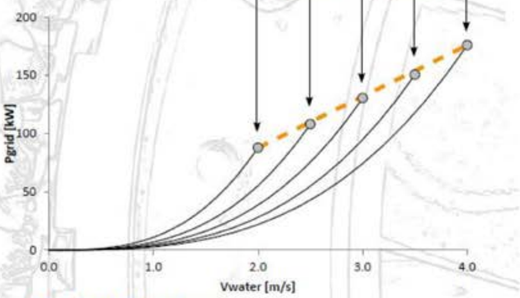
Tocardo International BV - Sluiskolkkade 2, 1779GP, Den Oever, The Netherlands (head office)
P: +31-226-42 34 11 - E: sales@tocardo.com - W: www.tocardo.com
-- new office address!! (from nov 1st 2011) --

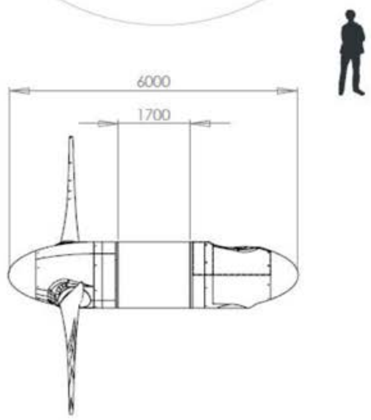
Tocardo T200



Operating data

		HT2.0	HT2.5	HT3.0	HT3.5	HT4.0
Rated water velocity	[m/s]	2.00	2.50	3.00	3.50	4.00
Blade D	[m]	9.2	7.3	6.1	5.2	4.6
Swept area	[m²]	66.5	41.9	29.2	21.2	16.6
Rated grid power	[kW]	87	109	131	153	174
Rated revs	[rpm]	22	27	33	39	44
Cut-in water speed	[m/s]	0.4	0.5	0.6	0.7	0.8
Cut-out water speed	[m/s]	2.6	3.8	4.5	5.3	6.0
Survival water speed	[m/s]	4.0	5.0	6.0	7.0	8.0





Nacelle dimensions

Diameter	[m]	1.40				
Length (nose-tail)	[m]	6.00				
Weight (dry)	[kg]	11400	11300	11200	11100	11000
Foundation mount		Bolted flange type				

Power cabinet dimensions

Space required	WxDxH	2.0 x 0.8 x 2.3
Weight	[kg]	1500
Environmental conditions		Protected environment, non-condensing, properly vented

Other infomation

General

Number of blades	2
Power regulation	Fixed pitch, variable speed, stall regulated
Directionality	Uni- & bi-directional
Power curve up to Vrated	3rd order, constant lambda
Power curve above Vrated	3rd order, stall regulated (overdrive mode)

Generator

Type	20-pole, permanent magnet, direct drive, variable speed
Model	Tocardo DD1000HT

Power conversion

Converter type	Solid state AC-DC-AC conversion, IGBT drive
Feed-in voltage	400V (customisable)
Feed-in frequency	50 / 60

Specifications and energy yields are for information purposes only and do not represent any warranty or promise; data is subject to change without prior notice.

version T200-DD1000HT v1.2a

Company	Verdant Power, Inc.
Country	U.S. (also Canada, UK & Hong Kong)
Web address	www.verdantpower.com
Technology Name	Kinetic Hydropwer System (KHPS)
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	i) (gravity and hybrid designs) and ii) (not surface-piercing)
Is power generated during ebb and flood flows	Yes
Features / Design principle	The KHPS uses a yawing turbine with a fixed-pitch 3 bladed rotor that is scalable from 50 to 500kW, and can be mounted individually on piles, gravity bases or triframes of 3 turbines.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	1/6 scale rotor design tests at US Navy David Taylor 1981, 1982. 3m diameter rotor vessel drag tests in Chesepeake and New York East River in 2001 - 2003. 5m diameter rotor; dynamometry and entire turbine system tests in East River at RITE Project, 2006-2008, 2.5m/s max. Grid-connected five-turbine array >70MWh (TRL 7/8)
Next development steps	Testing at our RITE project site in New York City of the Gen5 commercial turbines in 2012, then buildout to 30 turbines under FERC license. Scale Gen5 to the 10m-class *site-suited*[sm] systems.
Power train type	Induction generator - direct grid connection; future direct drive option
Dimensions	Test turbines have 5m diameter rotors, designs to 11m. TriFrame mounting structure starts at 2m high, 15m x 10m

Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	$19.63m^2$ (5m) to $78.54m^2$ (10m)
Weight of super structure (ton)	50mt to 200mt (TriFrame mounting)
Weight of power take off equipment (ton)	4.7mt to 14.1 mt (each turbine)
Min installation depth (m)	8 to 16
Max installation depth (m)	50
Design lifetime (years)	20
Cut in speed (m/s)	0.9 to 0.7
Rated flow speed (m/s)	site dependent: 2 to 4
Rated power (kW) at rated flow speed	56kW to 500kW
Maximum flow speed (m/s)	site dependent: 2 to 4
Current speed (m/s) vs electric power output (kWe) data points	see below for 5m dia. and 10m dia. Turbines
Estimated date commercially available	2013
Estimated production cost per rated unit (EUR)	€ 657,165 initial single unit cost for 10m
Have environmental impact studies been performed	Yes
Technical publications	Publications can be found at: www.theriteproject.com Complete publication list available.
Figures/photographs of device have been attached to reply	Photos available for download at: www.verdantpower.com and www.theriteproject.com
Could the device be combined with a suspension bridge fjord crossing / how?	Yes, with inverted pylon assembly.
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	Potential advantages: Avoids bottom charcteristics and slope issues; potential positioning in most desirable height in the water column. Potential disadvatages: Coupling of both weight and drag loads to the bridge; modal stability issues; ice.
Could the device be combined with a floating bridge fjord crossing / how?	Yes, possibly. With a combined floating platform mount, the bridge would take only extra drag forces, not support the turbine(s) weight. Possible use of added guys.

Advantages / disadvantages of combining the device with a floating bridge fjord crossing	Potential advantages: Avoids bottom charcteristics and slope issues; potential positioning in most desirable height in the water column. Potential disadvatages: Coupling of drag loads to the bridge; modal stability issues; ice.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes, if the structure is capable of supporting the turbine(s) using appropriate adaption.
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	Potential advantages: Combined econimics of sharing other structure; avoids bottom charcteristics and slope issues; potential positioning in most desirable height in the water column; convenient cabling. Potential disadvatages: Coupling of drag loads to the bridge; modal stability issues; corrosion issues.

	Electric Power Output (kWe) (per Turbine)	
Current Speed (m/s)	**5m**	**10m**
0.7	0	5
0.8	2	7
0.9	3	11
1	4	14
1.1	5	
1.2	6	
1.3	8	
1.4	10	
1.5	12	49
1.6	15	
1.7	18	
1.8	21	
1.9	25	
2	29	115
2.1	33	
2.2	38	
2.3	44	
2.4	50	
2.5	56	225
2.6	63	
2.7	71	
2.8	79	
2.9	85	
3	85	389

3.1	85	429
3.2	85	472
3.3	85	500
3.4	85	500
3.5	85	500

Source - www.verdantpower.com

Company	Voith Hydro Ocean Current Technologies GmbH & Co. KG
Country	Germany
Web address	http://www.voithhydro.com
Technology Name	HyTide
Device Type ** A) Horizontal Axis Turbine B) Cross-Axis Turbine C) Oscillating Hydrofoil D) Enclosed Tips (Venturi) E) Other Designs	A
Method to fix the device ** i) Seabed Mounted/Gravity Base ii) Pile Mounted iii) Floating (Flexible Mooring, Rigid Mooring, or Floating structure) iv) Hydrofoil Inducing Downforce	Device can be intergrated in several types of foundation. Experience so far with monopile and gravity
Is power generated during ebb and flood flows	Yes
Features / Design principle	The Voith HyTide is designed under the main principle of robustness and simplicity. The technology needs to provide a low-maintenance plant in order to minimize expensive offshore operations for maintenance and repair work. Therefore the basic principle is to keep complex systems and components out of the turbine and to focus on simple, robust and reliable technology. To address this challenge the consortium has selected the Voith Hy Tide 1000 turbine with the following key-features: 1. Direct drive, gearbox-free coupling and a generator with permanent magnet excitation 2. Three-bladed rotor with symmetric blades and variable speed for operation in the two main directions of the tidal flow, avoiding failure-prone pitch and yaw requirements 3. Elimination of grease through seawater lubrication bearing technology, ensuring environmentally friendly operation The small number of components lead to a robust turbine and thus to presumably lower life cycle costs of a tidal power plant consisting of multiple of these turbines. The Voith Hy-Tide 1000 Turbine generator works as an electrical motor to start the turbine from a defined minimum of the tidal speed and as well as the turbine brake. The bearings need no sealing against the external medium sea water. Instead it uses sea

	water itself for setting up a lubricating hydrodynamic film. Thus complex measures for sealing and periphery such as leakage water pumps are not required. The machine is protected by proven protective coatings and sacrificial anodes from corrosion and maritime fouling.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	In early 2011 Voith Hydro Ocean Current Technologies GmbH has successfully installed, grid-connected, commissioned and tested a prototype scale tidal turbine at Jindo in South Korea. The 1:3 scale prototype has a rated power of 110 kW and is fixed on a concrete gravity based foundation. Parallel to this prototype development Voith Hydro has started to develop a 1 MW full scale pre commercial test device which will be ready for installation in late summer 2012. The monopile foundation has been installed already in summer 2011 at the European Marine Energy Center, using a revolutionary environmental friendly subsea drilling technology. The drill unit has been operated from a special offshore construction vessel that is using Voith Schneider propulsion units to keep in position. In early 2011 Voith Hydro Ocean Current Technologies GmbH has successfully installed, grid-connected, commissioned and tested a prototype scale tidal turbine at Jindo in South Korea. The 1:3 scale prototype has a rated power of 110 kW and is fixed on a concrete gravity based foundation. Parallel to this prototype development Voith Hydro has started to develop a 1 MW full scale pre commercial test device which will be ready for installation in late summer 2012. The monopile foundation has been installed already in summer 2011 at the European Marine Energy Center, using a revolutionary environmental friendly subsea drilling technology. The drill unit has been operated from a special offshore construction vessel that is using Voith Schneider propulsion units to keep in position.
Next development steps	Next step will be to test the technology in a park/array configuration with several units of at least 3
Power train type	Direct drive generator
Dimensions	1MW unit: Length of nacelle 17 m Rotor diameter varaing according to flow caracteristics from 13-16 m

Area of current flow used by the device (m2) Shroud inlet area for an enclosed tips turbine Swept area of the turbine blades for an unshrouded turbine Plan form area for a vertical axis turbine	201
Weight of super structure (ton)	90 (1MW)
Weight of power take off equipment (ton)	200 (1MW)
Min installation depth (m)	25 (absolute min 20 for smaller rotor) (1MW)
Max installation depth (m)	60 (1MW)
Design lifetime (years)	20 (1MW)
Cut in speed (m/s)	1
Rated flow speed (m/s)	2.9
Rated power (kW) at rated flow speed	1000
Maximum flow speed (m/s)	5
Current speed (m/s) vs electric power output (kWe) data points	See below
Estimated date commercially available	2012-08
Estimated production cost per rated unit (EUR)	
Have environmental impact studies been performed	Yes
Technical publications	Tidal Current Energy Converter: On the challenge of effective and comprehensive characterization of complex met-ocean conditions and combinations thereof in a Basis of Design, Hydrovision, Sacramento, California, USA 2011 Arlitt, R.: Third Party Verification: Assessments, Certification, Classification and Marine Warranty Survey of a Tidal Project, Hydrovision, Sacramento, California, USA 2011 Arlitt, R.: Tidal Current Energy Projects Due Diligence: Energy Extraction Modelling, All-Energy, Aberdeen, UK 2011 Biskup F., Daus P., Arlitt R., Auslegung und Evaluierung eines Rotordesigns für Gezeitenströmungsanlagen, 5. Deutsche Meeresenergieforum, Dresden 2011 Daus P., Sepri M., Biskup F., Arlitt R., Methoden zur Ermittlung und Bewertung von Standortdaten für die Nutzung der Gezeitenströmungsenergie, 5. Deutsche Meeresenergieforum, Dresden 2010 Arlitt, R.: Meeresenergie – Energieformen, Stand der Technologie, Entwicklungsperspektiven, „ENERGIE“, Vortragsreihe Thema Energie des

	Studiengangs Bauingenieurwesen 2010 Arlitt R.: A New Case Study in Tidal Current Resource Monitoring, Analysis and Modelling, 4th International Tidal Energy Summit & Awards, London 2010 Arlitt R.: How to Overcome Real Tidal Technology and Engineering Challenges, Panelist, 4th International Tidal Energy Summit & Awards, London 2010 Arlitt R., Argyriadis K.: Certification of Tidal Current Power Plants, International Conference on Ocean Energie 2010, Bilbao 2010 Arlitt R.: Resource Assessment of Tidal Current Flows and its consequences on power plant technology, Hydro Vision 2010, Charlotte Convention Center – Charlotte, NC USA 2010 Arlitt R.: Fortschritte in der Nutzung der Wellen- und Gezeitenströmungsenergie, Vorlesung Meeresenergien, Hochschule Biberach, Biberach 2010 Arlitt R.: Meeresenergieprojekte bei Voith Hydro, 3. Deutsches Meeresenergieforum, 25-26. März 2010, Haus der Wissenschaften, Bremen 2010 Arlitt R.: Wellenenergie, Gezeitenströmungsenergie, Lecture Ocean Energies, TU Hamburg-Harburg 2009 Arlitt R.: Resources Assessment of Tidal Current Flows and implications to tidal current power plants, 33rd International Association of Hydraulic Engineering & Research (IAHR) Biennial Congress, Vancouver, British-Columbia, Canada
Figures/photographs of device have been attached to reply	Yes
Could the device be combined with a suspension bridge fjord crossing / how?	Yes - has to be discussed in detail. Especially on acceptable loads on the bridge crossing.
Advantages / disadvantages of combining the device with a suspension bridge fjord crossing	double use of supoprt structure, accessability and ease of cabling and grid connection
Could the device be combined with a floating bridge fjord crossing / how?	Yes.
Advantages / disadvantages of combining the device with a floating bridge fjord crossing	See above on the fixed bridge crossing combination. Needs investigations in detail.
Could the device be combined with a submerged floating tunnel fjord crossing / how?	Yes
Advantages / disadvantages of combining the device with a submerged floating tunnel fjord	See above on the fixed bridge crossing combination. Needs investigations in detail

Current Speed (m/s)	**Electric Power Output (kWe)**
0.05	0
0.15	0
0.25	0
0.35	0
0.45	0
0.55	0
0.65	0
0.75	0
0.85	0
0.95	0
1.05	0
1.15	59
1.25	76
1.35	96
1.45	119
1.55	145
1.65	175
1.75	209
1.85	247
1.95	289
2.05	336
2.15	387
2.25	444
2.35	506
2.45	573
2.55	646
2.65	725
2.75	810
2.85	902
2.95	1000
3.05	1000
3.15	1000
3.25	1000
3.35	1000
3.45	1000
3.55	1000
3.65	1000
3.75	1000
3.85	1000
3.95	1000
4.05	1000
4.15	1000
4.25	1000
4.35	1000
4.45	1000
4.55	1000

4.65	1000
4.75	1000
4.85	1000
4.95	1000
5.05	1000

Appendix 4: WEC device request for information

Dear Sir or Madam:

SP Technical Research Institute of Sweden has been commissioned by the Norwegian Public Roads Administration in a project that will potentially utilize a large number of wave energy conversion devices. We are currently in the process of performing a technology survey to determine the capabilities and characteristics of the different devices that are being developed. Upon review of the information available on the internet it seems that your technology is potentially promising for our application. We have developed a short questionnaire that we are asking all companies of interest to fill out in order to have an up-to-date basis for comparison of the different technologies. We would appreciate it if you could take the time to fill out the table below and send it back to me before February 3, 2012. If any of the information is not currently available then simply state that in your reply. A fictional sample reply is provided for your convenience and more information about some of the questions is given in the information below. I have also attached a copy of the questionnaire in excel format if you have any problems with the formatting of the table in the email when you reply.

For more information about the background of the project itself, please see the information below*. The results of this technology survey will be presented as part the workshop/conference scheduled for April 2012 (probably in Trondheim, Norway).

If you have any questions about the questionnaire or if you would like more detailed information about the project then feel free to contact me by replying to this email or calling at the number given below.

Best regards,

Daniel

Daniel Vennetti

SP Sveriges Tekniska Forskningsinstitut
SP Technical Research Institute of Sweden
Byggnadsteknik och Mekanik/Buildning Technology and Mechanics
Box 857, SE-501 15 Borås, Sweden
Tel: +46 (0)10 516 50 00, (direct) +46 (0)10 516 57 83
E-post: daniel.vennetti@sp.se
Internet: www.sp.se

	Fictional Sample Reply
Company	SP - Technical Research Institute of Sweden
Country	Sweden
Web address	http://www.sp.se/en/Sidor/default.aspx
Technology Name	SP Wave Technology
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	A
Features / Design principle	SP Wave Technology has three platforms that are attached with hinges and hydraulic cylinders both above and below the platforms. The up and down motion of the waves results in high pressure sea water, which turns a generator.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:10 scale proof-of-concept model was tested at SP's wave laboratory in Borås Sweden 2007-10. A 1:5 scale model including the proposed mooring system was tested at SP's Big wave laboratory in Borås, Sweden 2009-11. A full scale model is currently being tested including a new and improved mooring system off the east coast of Borås, Sweden which has an avg annual wave power density of 15 kW/m. The full scale model was deployed 2010-06 and has been generating power to the grid for over 4000 hours.
Next development steps	We have a spot reserved off the west coast of Borås, Sweden which has an avg annual wave power density of 30 kW/m. Testing is expected to begin in 2012-07
Power take off	Hydraulic using sea water

Dimensions	Each of the three sections is 10 m wide and has a length of 100 m, for a total length of 300 m.
Centerline device spacing for multiple devices (m)	75
Weight of super structure (ton)	200
Weight of power take off equipment (ton)	50
Min installation depth (m)	50
Max installation depth (m)	150
Design lifetime (years)	15
Rated power (kW) of commercial unit	1000
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	See below
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Numerical simulations
Estimated date commercially available	2015-01
Estimated production cost per rated unit (EUR)	5.00E+06
Have environmental impact studies been performed	Yes (see publications)
Discuss the survivability of the device and whether or not it has been tested.	The device equipped with a remote operated survival system. When a storm is approaching, the device automatically will detect that it should go into survival mode and will be filled with water so that it submerges until the storm has passed. This system has been tested in the full scale model that is currently being off the east coast of Borås Sweden and has worked flawlessly.
Technical publications	Vennetti D. Power predictions of the SP Wave Technology,. Renewable Energy Review 2007;5(5)20-50. Vennetti D. SP Wave Technology Environmental Impact Study,. Environment Magazine 2011;2(20)15-35.
Figures/photographs of device have been attached to reply	Yes (not actually true for this fictional example)
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	This device is best suited for offshore applications and it would be very difficult to combine with a fjord crossing structure.

Fictional Sample Reply
Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p)

T_p (s)

H_s (m)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	1000	964	789	822	0	0	0	0	0
6	0	0	0	0	0	0	0	0	1000	900	821	844	700	635	0	0	0	0
5.5	0	0	0	0	0	0	0	0	950	846	856	709	643	533	0	0	0	0
5	0	0	0	0	0	0	0	1000	858	854	708	643	532	525	440	0	0	0
4.5	0	0	0	0	0	0	1000	845	834	693	631	520	509	425	399	0	0	0
4	0	0	0	0	0	821	777	780	659	605	499	481	452	377	315	263	0	0
3.5	0	0	0	0	0	769	757	669	561	525	440	416	347	288	261	219	0	0
3	0	0	0	0	560	565	556	492	457	441	367	305	277	231	192	160	133	0
2.5	0	0	0	0	550	456	468	427	365	307	280	232	193	160	133	112	100	0
2	0	0	0	0	350	320	300	273	260	216	180	149	124	103	85	72	57	0
1.5	0	0	0	250	231	215	191	172	147	121	101	84	69	57	48	40	27	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Your Reply
Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p)

T_p (s)

H_s (m)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10																		
9.5																		
9																		
8.5																		
8																		
7.5																		
7																		
6.5																		
6																		
5.5																		
5																		
4.5																		
4																		
3.5																		
3																		
2.5																		
2																		
1.5																		
1																		
0.5																		
0.13																		

* **Project Background**

E39 is a road that is located on the west coast of Norway and extends from Kristiansand in the south to Trondheim in the north. Currently, a number of ferry crossings are required to traverse its entire length. The Transport Ministry has given a mandate for the project “Ferry Free E39” to assess the technological solutions for the crossing of eight large fjords without ferries. The fjords crossings range from 1.5 km to 25 km in length and have depths up to 1300 m. Proposed solutions for the crossings that are under consideration consist of suspension bridges, floating bridges, submerged floating tunnels, and sub-sea rock tunnels. Part of the project is to consider how the construction of the crossings can be combined with devices that produce energy from waves, tides, wind and the sun. The idea is that by using the bridge construction as part of the facility, the costs of the renewable power plants could be reduced and therefore be more competitive with non-renewable energy sources. If it is not possible to combine certain technologies with the actual bridge construction, the possibility will also be considered to install the devices in other locations, such as offshore.

Questionnaire Information

**** Device Type**

More information about the classification of device types can be found at the European Marine Energy Centre (EMEC) website at the following address:

http://www.emec.org.uk/wave_energy_devices.asp

***** Development status**

The development status of the project should be classified using the following technology readiness levels, which were obtained from the U.S. department of energy website at the following address:

http://www1.eere.energy.gov/water/hydrokinetic/usingDB.aspx

TRL 1-3: Discovery / Concept Definition / Early Stage Development, Design and Engineering

TRL 1-2: These are the lowest levels of technology readiness. Scientific research begins to be translated into applied research and development where basic principles are observed and reported. Technology concept and application are formulated and investigated through analytic studies and in-depth investigations of principal design considerations. This stage is characterized by paper studies, concept exploration, and planning.

TRL 3: In this stage, active research is initiated, including engineering studies and laboratory studies to physically validate analytical predictions of separate elements of the technology.

The purpose of this stage is to evaluate, insofar as possible, the scientific or technical merit and feasibility of ideas that appear to have commercial potential.

TRL 4: Proof of Concept

In this stage basic technological components of a sub-scale model are integrated to validate design predictions and system level functionality. The models, or critical subsystems, are tested in a laboratory environment.

This TRL represents early stage proof-of-concept system or component development, testing and concept validation. In this stage, critical technology elements are developed and tested in a laboratory environment. It is envisioned that scale models will be at 1:10 scale or smaller.

TRL 5/6: System Integration, and Technology Laboratory Demonstration

TRL 5: At this level, basic technological components are fabricated at a scale relevant to full scale and integrated to establish and verify subsystem and system level functionality and preparation for testing in a simulated environment.

TRL 6: At this level, representative model or prototype system at a scale relevant to full scale, which is beyond that of TRL 5, is tested in a relevant environment. This stage represents a major step up in a technology's demonstrated readiness and risk mitigation and is the stage leading to open water testing.

At this stage device, system, and subsystem level interfacing/integration testing represent a vital stage in technology development, and must be demonstrated. Models should be at a relevant scale (1:1 – 1:5) to reflect the challenges and realities of the full scale (1:1) system. Model testing is to be performed in a test facility capable of producing simulated waves/currents and other operational conditions while monitoring device response and performance. Furthermore, the devices foundation concept shall be incorporated and demonstrated.

TRL 7/8: Open Water System Testing, Demonstration, and Operation

TRL 7: At this level, the prototype scale components and subsystems are fabricated and integrated to establish and verify subsystem and system level functionality and preparation for testing in an open water operational environment to verify expected operation and fine tune the design prior to deployment in an operational demonstration project.

TRL 8: At this level, the prototype in its final form (at or near full scale) is to be tested, and qualified in an open water environment under all expected operating conditions to demonstrate readiness for commercial deployment in a demonstration project. Testing should include extreme conditions.

At this stage, the device model scale is expected to be at or near full scale (1:1 – 1:2). Testing may be initially performed in water at a relatively benign location, with the expectation that testing then be performed in a fully exposed, open water environment, where representative operating environments can be experienced. The final foundation/mooring design shall be incorporated into model testing at this stage.

DOE TRL 9: Commercial-Scale Production / Application

At this stage, the actual, commercial-scale system is proven through successful mission operations, whereby it is fielded and in-use in commercial application. This stage represents an in-service application of the technology in its final form and under mission condition

****** Wave energy absorption performance**

The wave energy absorption performance should be based on numerical simulation or random wave model tests. Useful information about how to convert data that is characterized by mean zero-crossing period to peak period characterization and how to extrapolate simulated or tested performance data to other sea states is discussed on pages 9 and 10 in the EPRI Guidelines for Preliminary Estimation of Power Production by Offshore Wave Energy Conversion Devices. This can be found at the following address:

http://oceanenergy.epri.com/attachments/wave/reports/001_WEC_Power_Production.pdf

Appendix 5: WEC device list of developers

Table A5:1 WEC device developers.

Technology Developer	**Confirmed Contact**	**Responded to RFI**
Able Technologies L.L.C.		
AeroVironment Inc		
AlbaTERN		
Applied Technologies Company Ltd		
Aquamarine Power		
Aquagen Technologies		
Aqua-Magnetics Inc		
Atargis Energy Corporation		
Atmocean		
AW Energy		
AWS Ocean Energy		
BioPower Systems Pty Ltd		
Bourne Energy		
Brandl Motor		
Carnegie Wave Energy Limited		
Checkmate Seaenergy UK Ltd.		
Columbia Power Technologies		
Dartmouth Wave Energy		
DEXA WAVE Energy Aps		
Ecofys		
Ecomerit Technologies		
Embley Energy		
ETYMOL		
Euro Wave Energy		
Float Inc.		
Floating Power Plant A/S		
Fred Olsen Ltd		
GEdwardCook		
Grays Harbor Ocean Energy Company		
Green Ocean Wave Energy		

Greencat Renewables		
Hann-Ocean		
HidroFlot SA		
Indian Wave Energy Device		
Instituto Superior Tecnico		
Intentium AS		
Interproject Service (IPS) AB		
Kinetic Wave Power		
Langlee Wave Power		
Leancon Wave Energy		
Motor Wave		
Navatek Ltd		
Neptune Renewable Energy Ltd		
Nodding Beam = Power		
Ocean Energy Industries, Inc.		
Ocean Energy Ltd		
Ocean Harvesting Technologies		
Ocean Motion International		
Ocean Power Technologies		
Ocean Wave Energy Company		
Oceanlinx		
Offshore Islands Limited		
Offshore Wave Energy Ltd		
Ocean Wave and Wind Energy (OWWE) - INNOVAKO		
OWC Power		
Pelagic Power AS		
Pelamis Wave Power		
PerpetuWave Power Pty Ltd		
Pontoon Power		
Protean Energy Limited		
Renewable Energy Pumps		
Resolute Marine Energy, Inc		
Sara Ltd		

SDE		
Seabased AB		
SeaNergy		
Sea Power Ltd		
Seatricity		
Seawood Designs Inc		
Straumekraft AS		
Swell Fuel		
Trident Energy Ltd, Direct Thrust Designs Ltd		
Vigor Wave Energy AB		
Voith Hydro Wavegen		
Wave Dragon		
Wave Energy AS		
Wave Energy Fyn		
Wave Energy Technologies Inc.		
Wave Star Energy ApS		
Waveberg Development		
WaveBob Limited		
WavePiston		
Waves4Power		
Wello OY		
Weptos		

Appendix 6: WEC device responses

Table A6:1 WEC device basic information.

Technology Developer	**Technology Name**	**Device Type**	**Country**	**Rated Power (kW)**
Applied Technologies Company Ltd	Float Wave Electric Power Station	G	Russia	10-12000
AquaGen Technologies	SurgeDrive	B	Australia	40000
Atargis Energy Corporation	Cycloidal Wave Energy Converter	G	USA	5000
Atmocean	Wave Energy/Sequestration Technology ("WEST")	B	USA	1000
AW-Energy Oy	WaveRoller	C	Finland	500
BioPower Systems Pty Ltd	bioWAVE	C	Australia	1000
Hann-Ocean Energy Pte Ltd	Drakoo	G	Singapore	4-1000
MotorWave group	MotorWave	G	Hong Kong	16
Ocean Energy Industries, Inc.	WaveSurfer	B	USA	0.5-10000
Ocean Harvesting Technologies AB	Ocean Harvester	B	Sweden	100-150
OWWE - INNOVAKO	Floating Bridge	-	Norway	-
OWWE - INNOVAKO	OWWE-Rig	E	Norway	5000
OWWE - INNOVAKO	Wave Pump-Rig	B	Norway	-
OWECO Ocean Wave Energy Company	OWEC® Ocean Wave Energy Converter	B	USA	30-2150
Oceanlinx Ltd	greenWAVE/ogWAVE/blueWAVE	D	Australia	500-2500
PerpetuWave Power Pty Ltd	Wave Harvester	A / B	Austrailia	850-1500
RESEN ENERGY	LOPF wave energy buoys	B	Denmark	300
Resolute Marine Energy, Inc	SurgeWECTM	C	USA	30
Sea Power Ltd	Sea Power Platform	A	Ireland	3750
Seatricity	Oceanus	A/B	UK	30-300
Seawood Designs Inc	SurfPower	B	Canada	300

Shamil Ayntrazi	Wind, Wave, Tidal and Deep Sea Water Air Conditioning	G	USA	90
Trident Energy Ltd	Wave Energy technology	A	UK	40-150
Vigor Wave Energy AB	Vigor Wave Energy Converter	G	Sweden	3-100000
Voith Hydro Wavegen	-	D	Scotland	18.5-132
Waveenergyfyn	Crestwing	G	Denmark	200
Wavestar A/S	Wave Star	B	Denmark	600
Waveberg Development	Waveberg	A	USA	125
WavePiston ApS	WavePiston	G / A	Denmark	30-1000
W4P Waves4Power AB	WaveEL-buoy	B	Sweden	250
Wello Ltd.	Penguin	G	Finland	1000

In the table, the device types are identified as follows: A= Attenuator, B=Floating point absorber, C=Oscillating wave surge converter, D=Oscillating water column, E = Overtopping/terminator, F=Submerged pressure differential and G=Other designs.

Company	Applied Technologies Company Ltd
Country	Russia
Web address	www.atecom.ru
Technology Name	Float Wave Electric Power Station (FWEPS)
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	G: Matched Load
Features / Design principle	The FWEPS concept uses the advanced approach when the process of energy conversion is based on efficient interaction of wave energy source and oscillatory loading mechanism intrinsic for the case. The module of FWEPS is a vertically oriented, oblong axisymmetrical capsule-float located on sea surface. Inside the capsule there are a mechanical converter consisting of an oscillatory system and drive; an electric generator and energy accumulator. Under waves effect the capsule-float and inner oscillatory system of a mechanical converter are in continuous oscillatory motion, while the drive engaged with the system provides a continuous spin-up of an electric generator. Owing to its peculiarity, the device is matchable with outer wave space that gives the most effective mode for energy taking-off and sustainable operation at varying wave harsh conditions. Depending on the mission it is possible to develop both a single modular FWEPS for output power up to 50 kW and multi-modular plant designed for the total electric power of the order of some dozens of megawatts.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 4

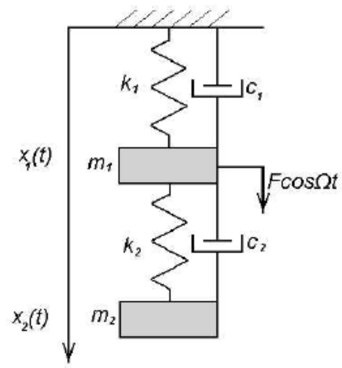
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	FWEPS scaled models were tested in the laboratory and seakeeping basin. The research has shown that: • FWEPS using an oscillatory drive as the main unit enables to be considered a perspective device for wave energy conversion to electricity and owing to its features and arrangement advantages it can secure the best condition for effective wave energy taking-off. • The mechanical actuator with an oscillatory system being one of its main parts can be effectively used as a drive for an electric generator in the given type of energy converter. • The study of FWEPS model irregular-sea behavior at Sea States 4…5 numbers performed in the sea keeping basin with wavemaker has demonstrated the device survivability in stormy condition. As a whole the research has shown that the device is basically serviceable for effective wave energy conversion and survivable in stormy condition.
Next development steps	Phase 1: Development of full scaled 10…50 kW FWEPS module (2.0 ÷ 2.5 years). Phase 2: Development of multimodule grid installation of not less than two megawatt output power (3 ÷ 4 years).
Power take off	Oscillatory drive-actuator
Dimensions	The 10 kW FWEPS module of cylindrical shape is of 2.5 m in diameter and 12 m in length.
Centerline device spacing for multiple devices (m)	It depends on rated power of module and multimodule installation capacity.
Weight of super structure (ton)	For the 10 kW module: 20 (mainly ballast of metal products waste dominantly)
Weight of power take off equipment (ton)	For the 10 kW module: 2
Min installation depth (m)	40
Max installation depth (m)	No limitation.
Design lifetime (years)	20…30
Rated power (kW) of commercial unit	Depending on the mission it is possible to develop both a single modular FWEPS for output power up to 50 kW and multi-modular plant

	designed for the total electric power of the order of some dozens of megawatts.
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	See below
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Numerical simulations and wave model tests
Estimated date commercially available	2015-01
Estimated production cost per rated unit (EUR)	The cost of power units will be not more than 2500 EUR/kW, depending on place and conditions of operation.
Have environmental impact studies been performed	Yes, preliminary. Wide application of FWEPS will facilitate the removal of reasons aggravating the hotbed and climate warming up effects, thus promoting the environment rehabilitation and life improvement.
Discuss the survivability of the device and whether or not it has been tested.	The study of FWEPS model irregular-sea behavior at Sea States 4…5 numbers performed in the sea keeping basin with wavemaker has demonstrated the device survivability in stormy condition. One of FWEPS competitive advantages is reliability and long useful life because of waterproof capsulefloat protects elements of the device from corrosive attack of sea water and its vapour.
Technical publications	See Below
Figures/photographs of device have been attached to reply	Yes photographs of device are given in Appendix.
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	This device is best suited for offshore applications and it is possible to combine it with a fjord crossing structure.

Research and development on ocean energy exploitation is underway in many countries around the world. A number of ongoing works on wave energy technologies is very large. However principles of devices operation can be reduced to a few recognized basic models (Device Types): Attenuator, Point Absorber, Oscillating Wave Surge Converter, Oscillating Water Column, Overtopping/Terminator Device and Submerged Pressure Differential. All these devices are well suited for wave energy take off only at particular/regular wave conditions.

Regrettably ocean energy conversion technologies have not progressed yet to massive power generation. This is because of installations operational principles are based mainly on passive wave – device interaction that cannot be effective in view of irregularity of wave forming process, which interferes with efficient wave power utilization. Difficulties facing wave power utilization issued from inconstancy of wave amplitude, phase and direction of propagation at a wide range of excitation frequencies (wave lengths) in real harsh marine environment. Due to stochasticity of vortex air flows the energy of wind waves system varies both in time and with distance/direction of propagation. It is difficult to couple these sea wave's peculiarities with intention to obtain maximum efficiency and serviceability of a device.
Obviously the design of a wave power converter has to be highly sophisticated to meet these requirements or, in other words, to be operationally serviceable, efficient, reliable and economically acceptable simultaneously in a stormy aqua area.
That is why the correct evaluation of Wave energy absorption performance is to be carried out via approach when characteristics of device and wave space are matched as well as parameters of device-wave interaction are taken into account. The sample of such kind estimation is given below.

From the natural science standpoint, seawaves is the most visible example of creature characterized by space-time variability of their properties. As with any oscillatory-wave process, the best facility for wave energy take-off is an oscillatory device matched with outer wave space. For this reason, FWEPS is a very promising device for wave energy conversion to electricity since, in accordance with the given rule, it employs the matched oscillatory drive as an electric generator actuator, thus securing efficient interaction of wave energy source and oscillatory load intrinsic for the case.



FWEPS dynamic model: The oscillating system consists of a capsule-float able to oscillate in water and an elastic pendulum with a large mass weight suspended inside. The system can be simulated adequate enough by a two-degree-of-freedom oscillating model (see scheme).

◀Scheme of dynamic model of single-module FWEPS.
m_1 - mass of a capsule-float incorporating an added liquid mass,
m_2 - mass of the pendulum weight suspended inside the float;
x_1 and x_2 - shifts of masses;
k_1 - quasi-elasticity of fluid–float interaction,
k_2 - stiffness of an inner pendulum spring.

The sea wave effect on the float can be expressed by an external harmonic force:
$F = F_0 \cos\Omega t = k_1 h\cos\Omega t = \rho_w g S h\cos\Omega t$, where F_0 – the amplitude of the exciting force (here the amplitude of the oscillating component of the buoyancy force), h - the oscillating component of the capsule submerged length, ρ_w - sea water density, g - gravitational acceleration, S - cross-sectional area of the float, Ω - oscillation frequency of the exciting force.

As is seen, the buoyancy oscillating component provides a harmonic exiting action on the float due to its natural quasi-elasticity ($k_1 = \rho_w g S$). The hydrodynamic drag $c_1\dot{x}_1$ with damping coefficient of c_1 characterizes a fluid - float interaction force. The resistance force with damping coefficient of c_2 characterizes both the energy removed for the electric generator spin-up and the dissipation of energy inside of the float due to the internal friction losses.
The averaged power over the period which can be taken-off from the source can be defined by formula:
$P = \frac{1}{T}(-c_1\pi A_1^2\Omega - c_2\pi\Omega(A_1^2 + A_2^2 - \frac{A_1A_2}{2}\sin 2\varphi_1 \sin 2\varphi_2))$, where $A_{1,2}$ - amplitudes of weight shifts.

As it can be seen an average capacity of the FWEPS module is the function of eight parameters: $P = f(m_1, m_2, k_{1,} k_2, c_1, c_2, F, \Omega)$.

The availability of a great number of independent variables defining the wave converter operation makes the process simulation in a two degree oscillating system an extremely difficult task.
Thus for the preliminary determination of the hydrodynamic resistance coefficient (c_1) one should know the regularities and availability of experimental data for the body-water oscillatory interaction. The body-water interaction type depends on the shape of an underwater section; velocity of travel; oscillation frequency; the proportion of floater characteristic sizes to the amplitude of its oscillations and wave length; dynamics of hull – Stokes' viscous wave and Karman's vortices interaction; other factors.
Therefore when developing the process simulation it is reasonable to make use of its between-characteristic correlation. Thus, using the non-dimensional masses m_2/m_1 and stiffness of springs k_2/k_1 being structurally compatible, one can determine the accessible designed capacities of the device which will define both the shape and operation efficiency of the actuator.

A two degrees-of-freedom oscillation system is a complex mechanism in which a stable oscillatory motion is possible but at certain values of parameters and their relationships. At the same time the characteristics of the oscillating actuator as a technical device can be determined by defining its ability for energy transformation at the kinematical excitation of the inner pendulum (i.e. by oscillating the point of suspension with the given amplitude and frequency) without analysing the cause of such oscillations.

The whole scope of optimum parameters for the two-degree oscillating model and mechanical converter shall be calculated numerically upon conducting some model laboratory and scaled field experiments.
As an example, it is presented the results from a calculation of the main parameters of an FWEPS module for a wave with period T = 5 s (Ω = 1.2566 rad/s), length λ = 39 m, and height H = 1 m. Using significant wave heights and periods, one can to define a specific energy flux of irregular wind waves through a water area: $\mathrm{P}_s = \dfrac{\rho_w g^2}{64\pi} H_s^2 T_s \left[{kW}/{m}\right]$. To ensure vertical stability of the device, we take $\mu = m_2/m_1 = 0.25$, and damping coefficients $\psi_1 = \dfrac{c_1}{m_1}\sqrt{{m_1}/{k_1+k_2}}$ and $\psi_2 = \dfrac{c_2}{m_2}\sqrt{{m_1}/{k_1+k_2}}$ are taken as follows: $\psi_1 = 0,2$ and $\psi_2 = 0,4$. Bearing in mind that $k_1 = \pi D_c^2 dg/4$, $m_1 = k_1\xi_1/\Omega^2(1-\mu\xi_1)$, $m_2 = \mu m_1$ and $k_2 = \Omega^2 m_2$, at capsule diameter D_c = 1.37 m we determine optimal detuning factor $\xi = \dfrac{m_1}{m_2} \times \dfrac{k_2}{k_1+k_2} = 0{,}583$, amplitudes A_{10} =0,952 м, A_{20} =2,15 м as well as mean wave power $P_1(t)$ = 4.23 kW and mean useful power $P_2(t)$ = 2.73 kW. In this case wave energy utilization efficiency is equal to $\eta = P_2(t)/)P_1(t)$ = 0.645.
The converter's efficiency may be higher as compared with that estimated above. To achieve this, further experimental–theoretical simulation of the device and perfection of its design have to be carried out.

1. Temeev A.A. High Efficient Ecologically Pure Wave Electric Power Stations and Its Applications, Proceedings of the 32-th Intersociety Energy Conversion Engineering Conference. 1997. Vol.3, p.2001- 2004, Honolulu, Hawaii, USA.
2. Temeev A.A. and Sorokodoum E.D.. Unsteady Effects in Oscillatory Body – Water Interaction. Proceedings of the Conference the 4-th European Wave Energy Conference, December 4–6, 2000, Aalborg, Dk.
3. Temeev A.A., Antufyev B.A., Temeev S.A. Simulation of Oscillatory Drive for Float Wave Energy Converter. Proceedings of the Fifth European Wave Energy Conference, September 17th-20th 2003, Cork, Ireland.
4. Temeev A.A., Belokopytov V.P., Temeev S.A. Floating Wave Energy Converter and Electrolytic Hydrogen Production Integrated System. Proceedings of the World Renewable Energy Congress VIII, 29 August – 3 September, 2004. Denver, Colorado, USA.
5. Alexander A. Temeev, Victor P. Belokopytov, Sergey A. Temeev. An Integrated System of Floating Wave Energy Converter and Electrolytic Hydrogen Producer. Journal Renewable Energy 31 (2006) 225-239, © Elsevier Ltd.
6. Alexander Temeev, Oleg Sladkov, Sergey Temeev. Dynamic model of oscillatory drive for Floating Wave Energy Converter. Proceedings of the tenth World Renewable Energy Congress, 19-25 July 2008, Glasgow, Scotland.
7. Temeev A.A., Sladkov O.S., Temeev S.A. Dynamic Model of a Float Waves Energy Converter // Thermal Engineering, 2008, Vol. 55, No. 12, pp. 1017–1025. ISSN 0040-6015, © Pleiades Publishing, Inc.

Company	AquaGen Technologies

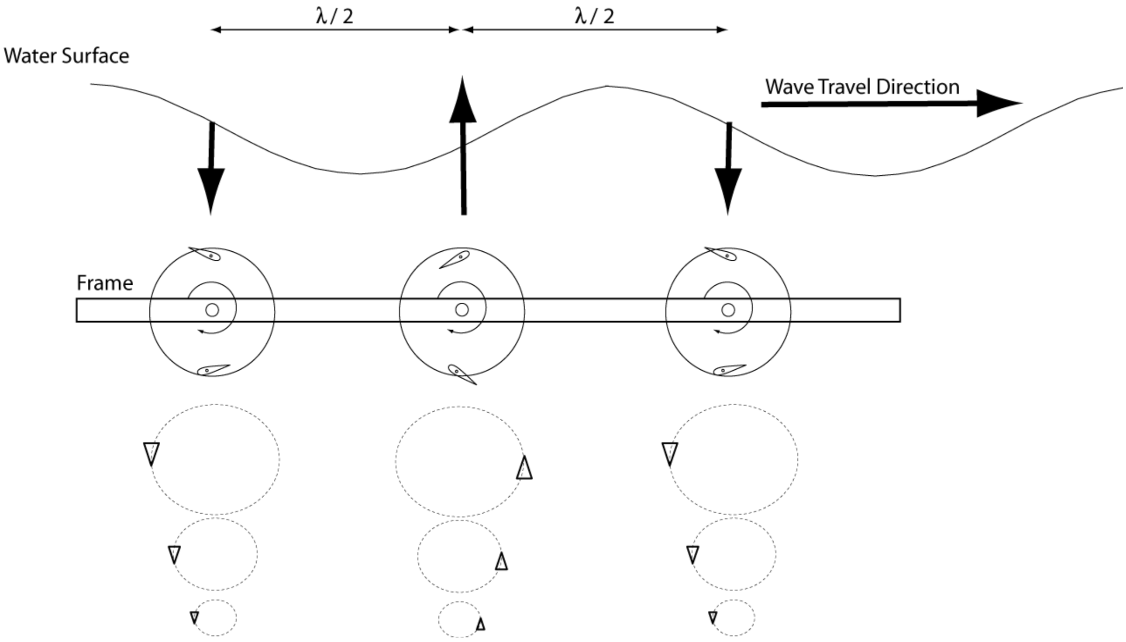
Country	Australia
Web address	www.aquagen.com.au
Technology Name	SurgeDrive
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B
Features / Design principle	As waves pass the buoyancy units of a SurgeDrive® wave farm, they move in oscillation and the system transfers the pure wave forces out of the water, via tension transfer elements. From there, the energy conversion module is able to use these forces to generate electricity or desalinated water, using an innovative mixture of design and 'off the shelf' components. This dramatically simplifies the capture of wave energy because most components are above water and underwater components are minimised and simplified. This leads to a significant reduction in capital expenditure (less expensive, corrosion resistant materials required), maintenance (hence lower electrical / desal generation costs) whilst also enabling the flexibility for the system to not only survive storms but to continue to generate during them.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	1. Small scale wave flume model testing, 2009/10, Monash University, Melbourne, Australia 2. Demonstration Trial of 1.5kw unit on Lorne pier, Victoria, Australia Nov 2010
Next development steps	Currently raising capital for next stage of development - a Full-Scale (limited expension) pilot demonstration. This will finalise and test the final full scale coponentry prior to the first large scale commercial wave farm.
Power take off	Hydraulic/Electric or Hydraulic/Desalinated water options
Dimensions	full size buoyancy units are 6m diameter each. 100's of these are tethered back to a central platform, a purpose-built pier or straight back to land to generate megawatts of electricity or gigalitres of desalinated water.
Centerline device spacing for multiple devices (m)	15m between buoyancy units in 20m water depth

Weight of super structure (ton)	depends on number of buoyancy units tying into Energy Conversion Module
Weight of power take off equipment (ton)	depends on number of buoyancy units tying into Energy Conversion Module
Min installation depth (m)	10
Max installation depth (m)	50
Design lifetime (years)	25
Rated power (kW) of commercial unit	40000kw or 40Mw for 400 buoyancy units in 45kw/m wave region This is just an example as it depends on local wave resource and marine area available.
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	The energy output of our technology is very high but is not publically available at this stage but can be disclosed privately under an NDA.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	scale model tests.
Estimated date commercially available	2014-01
Estimated production cost per rated unit (EUR)	USD $50 million for the rated 40Mw nameplate unit
Have environmental impact studies been performed	Yes, for our Lorne Pier Demonstration
Discuss the survivability of the device and whether or not it has been tested.	During extreme storm conditions, the SurgeDrive® control system automatically pulls the buoyancy units under the water to avoid storm damage and yet enable the continued generation of power.
Technical publications	N.Boyd, 'The Development of Wave Energy as a Viable Renewable Source', All-Energy Conference and Exhibition, Oct 2011 EcoGen 2011, Sept 2011
Figures/photographs of device have been attached to reply	Yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	This technology is suited to applications where there is an existing waterbourne strucutre such as a pier or bridge, provided that there are ocean waves passing close to that structure as it is not a tidal but a wave energy device.


PROHIBITED

Company	Atargis Energy Corporation
Country	USA
Web address	www.atargis.com
Technology Name	Cycloidal Wave Energy Converter
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	G. Lift based, fully submerged wave termination device with direct wave-to-shaft power conversion
Features / Design principle	two hydrofoils that rotate around a shaft alinged with the wave crests and operated under feedback control achieve wave termination
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 3 with TRL 4 work in progress
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:300 scale model was tested in a wave flume in 2010-2011. Presently, a 1:10 scale model is being tested in a 3D wave basin advancing this technology to TRL 4
Next development steps	TRL 5 work will start in the second half of 2012, and open ocean 1/4 scale tests are planned for mid-2013
Power take off	Generator, either with gear box or low speed direct drive
Dimensions	wave climate dependent, invisicid optimal diameter is about 30% of a wave length. Power output increases linearly with hydrofoil span
Centerline device spacing for multiple devices (m)	0
Weight of super structure (ton)	75
Weight of power take off equipment (ton)	45
Min installation depth (m)	25
Max installation depth (m)	100
Design lifetime (years)	20
Rated power (kW) of commercial unit	5000
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	The data requested in the wave performance tab is currently unpublished and proprietary. We have published an efficiency of >70% at the design point including viscous losses, and an invisicd efficiency of >95% which is experimentally confirmed.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Both

Estimated date commercially available	2016
Estimated production cost per rated unit (EUR)	5-10M Euro for a 5MW unit depending on site specifics, deployed
Have environmental impact studies been performed	No
Discuss the survivability of the device and whether or not it has been tested.	The CycWEC can be feathered in a storm, as well as be submerged deeper into the ocean to prevent storm damage. This will be experimentally demonstrated in TRL5
Technical publications	See publication list at: http://atargis.com/MoreInfo.html
Figures/photographs of device have been attached to reply	No, please refer to above web site
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Yes, the CycWEC can be attached to the substructure of a bridge if desired



Source - www.atargis.com

Company	Atmocean, Inc.
Country	USA
Web address	www.atmocean.com
Technology Name	Wave Energy/Sequestration Technology ("WEST")
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B (array)
Features / Design principle	Hydraulic system. Onshore generators. Patent-pending variable sea anchors suspended beneath each pump provide the resistance against buoy rising, to create the pressure fed into lateral pressure line. This means the pumps do not need individual moorings - a big cost saving. By operating in low waves (under 1m), annual availability is above 90% most locations. To prevent overstressing, above 3.5m wave the forces are capped. Designed for low cost - containerized for shipping - deployed from moving vessel no undersea operations needed - array moorings at each end.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 5/6 or 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	We have conducted 22 ocean tests of subsystems. Most recent sea trial at California Polytechnic State University 4 months 1/2 scale system, characterize input/output, evaluate durability, gain data on biofouling.
Next development steps	We are now completing the full-scale design drawings which are getting cost quotes from suppliers. We expect to initiate our environmental impact study in July 2012 by Rutgers University Coastal Ocean Observing Laboratory. This will be a 3 month analysis using a 10-pump moored array in the Atlantic 60km east of Tuckerton NJ. This system will generate power locally (on a small barge or raft) since transmitting the hydraulic pressure 60km to shore is not feasible for this pilot scale unit.
Power take off	Hydraulic using seawater

Dimensions	Each WEST unit is 20m deep, weighing about 1.5 metric tons excluding connecting hose. Adjacent WEST units are spaced 30m apart. A one MW array comprises 50 connected units. The connecting hose depth is ~10m. At end of array, the hose is allowed to sink to the seafloor where it extends (not buried) to shoreline. Beach crossing is a rigid pipe. The pressure line is then brought to the Power house Pelton motor connected to generator.
Centerline device spacing for multiple devices (m)	30m preliminary
Weight of super structure (ton)	0.5 metric tons approx.
Weight of power take off equipment (ton)	onshore Pelton motor weight tbd
Min installation depth (m)	30m preliminary
Max installation depth (m)	200m preliminary
Design lifetime (years)	overall 20 years. Some parts require periodic refurbishing each 1 to 5 years.
Rated power (kW) of commercial unit	one MW per array of 50 pumps
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	See output page
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Numerical calculations supported by Cal Poly sea trial data
Estimated date commercially available	2013
Estimated production cost per rated unit (EUR)	Under US $ one million per MW (50 pumps, connecting hoses, moorings, assembly, deployment, and Pelton motor but not shipping costs, onshore generator or power conditioning)
Have environmental impact studies been performed	Upcoming this summer-fall
Discuss the survivability of the device and whether or not it has been tested.	The system automatically submerges in waves above about 3.5m, to protect against storm damage and ensure stress limits are not exceeded. No external signal or forecast is needed. This function has not yet been tested.
Technical publications	None
Figures/photographs of device have been attached to reply	Yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Yes. The fjord crossing can act as one end of the array mooring, so it is simple to extend the array outward from the crossing and install a seabed mooring for the other end of the array. If a floating bridge or submerged tunnel, our hydraulic pressure line could be run adjacent to this structure rather

than lie on the seafloor.

Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p)
We calculate the volume pumped per wave based on the cylinder dimension of 0.2m diameter, by 2.5m height, giving a useful volume of 0.0785 cubic meters per full stroke.
In waves less than 2.5 m height, the volume pumped will be proportional to this cylinder volume.

H_s (m) \ T_p (s)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10.0	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
9.5	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
9.0	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
8.5	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
8.0	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
7.5	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
7.0	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
6.5	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
6.0	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
5.5	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
5.0	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
4.5	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
4.0	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
3.5	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
3.0	55	41	33	27	24	21	18	16	15	14	13	12	11	10	10	9	9	8
2.5	54.95	41.21	32.97	27.48	23.55	**20.61**	18.32	16.49	14.99	13.74	12.68	11.78	10.99	10.30	9.70	9.16	8.68	8.24
2.0	43.96	32.97	26.38	21.98	18.84	16.49	14.65	13.19	11.99	10.99	10.14	9.42	8.79	8.24	7.76	7.33	6.94	6.59
1.5	32.97	24.73	19.78	16.49	14.13	12.36	10.99	9.89	8.99	8.24	7.61	7.07	6.59	6.18	5.82	5.50	5.21	4.95
1.0	21.98	16.49	13.19	10.99	9.42	8.24	7.33	6.59	5.99	5.50	5.07	4.71	4.40	4.12	3.88	3.66	3.47	3.30
0.5	10.99	8.24	6.59	5.50	4.71	4.12	3.66	3.30	3.00	2.75	2.54	2.36	2.20	2.06	1.94	1.83	1.74	1.65
0.1	2.75	2.06	1.65	1.37	1.18	1.03	0.92	0.82	0.75	0.69	0.63	0.59	0.55	0.52	0.48	0.46	0.43	0.41

Average wave steepness (m/s)

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2.5	0.83	0.63	0.50	0.42	0.36	0.31	0.28	0.25	0.23	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.13
2.0	0.67	0.50	0.40	0.33	0.29	0.25	0.22	0.20	0.18	0.17	0.15	0.14	0.13	0.13	0.12	0.11	0.11	0.10
1.5	0.50	0.38	0.30	0.25	0.21	0.19	0.17	0.15	0.14	0.13	0.12	0.11	0.10	0.09	0.09	0.08	0.08	0.08
1.0	0.33	0.25	0.20	0.17	0.14	0.13	0.11	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05
0.5	0.17	0.13	0.10	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
0.1	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

diameter	**0.2**	m	height	2.5	m
	volume pumped per 2.5m wave			0.0785	m^3

kW = liters per minute * pressure (in bar)/600

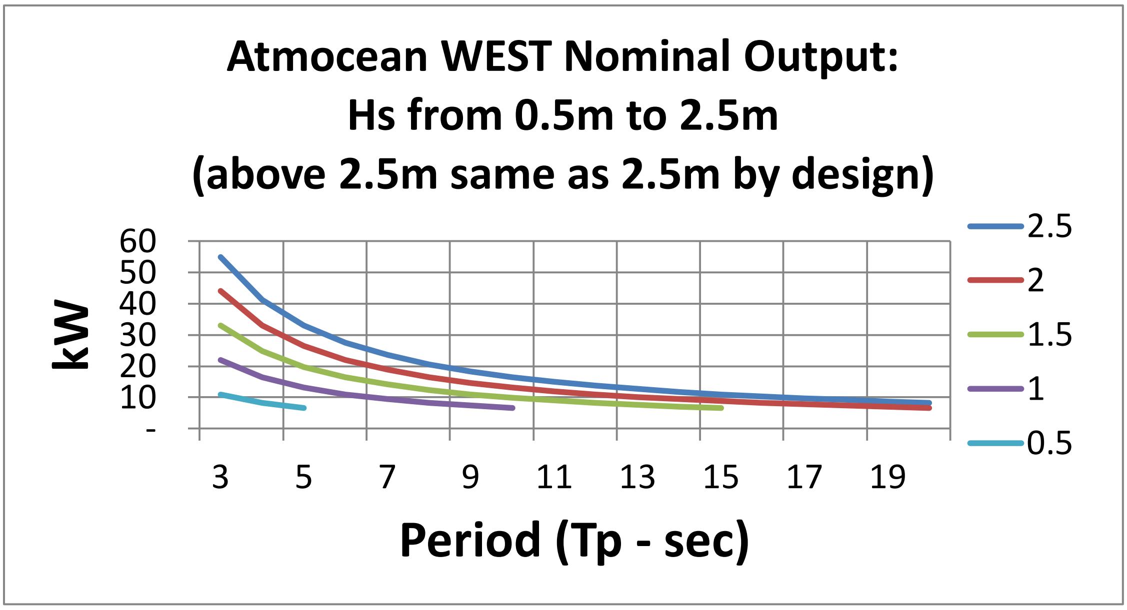
pressure designed for 21 bar

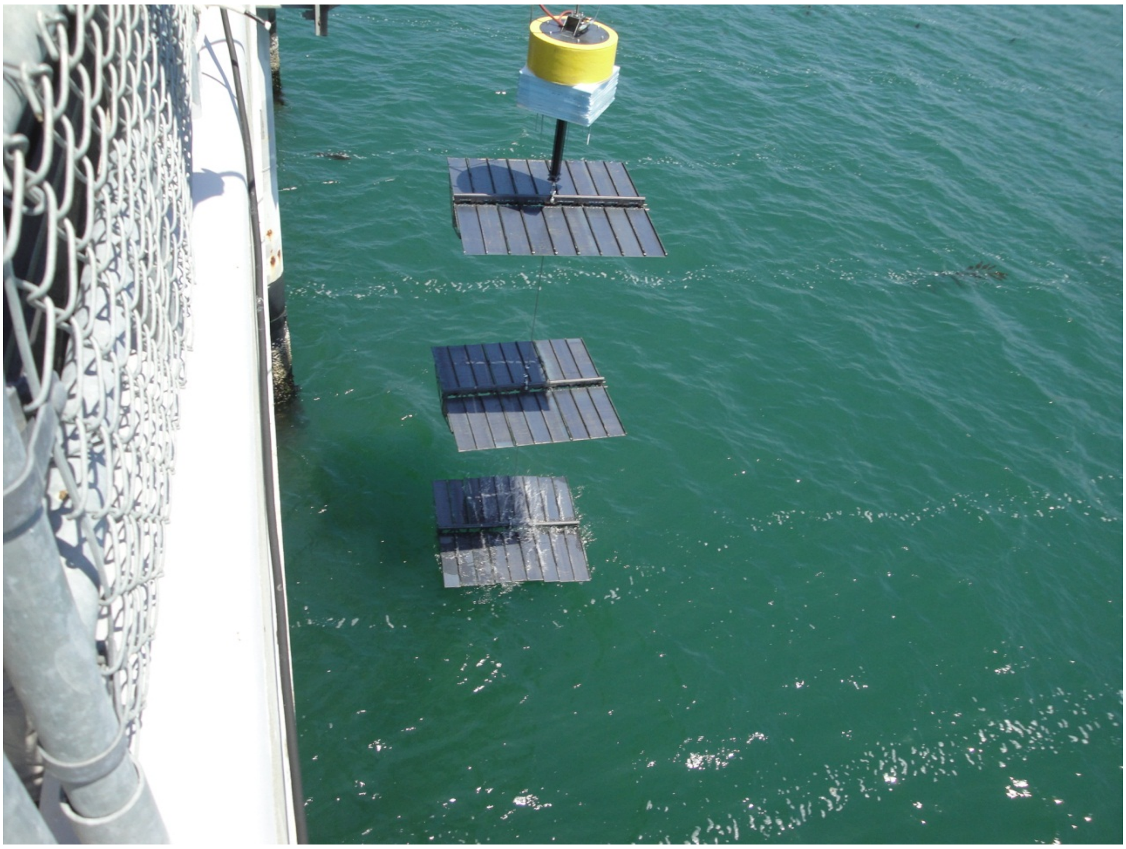
We base our nominal output on 2.5 wave @ 8 seconds)shown in bold large font in the table).

Our seatrials conducted at California Polytechnic State University last summer demonstrated needed.

that average wave steepness of 0.1 m/s is required to produce the pressure rise

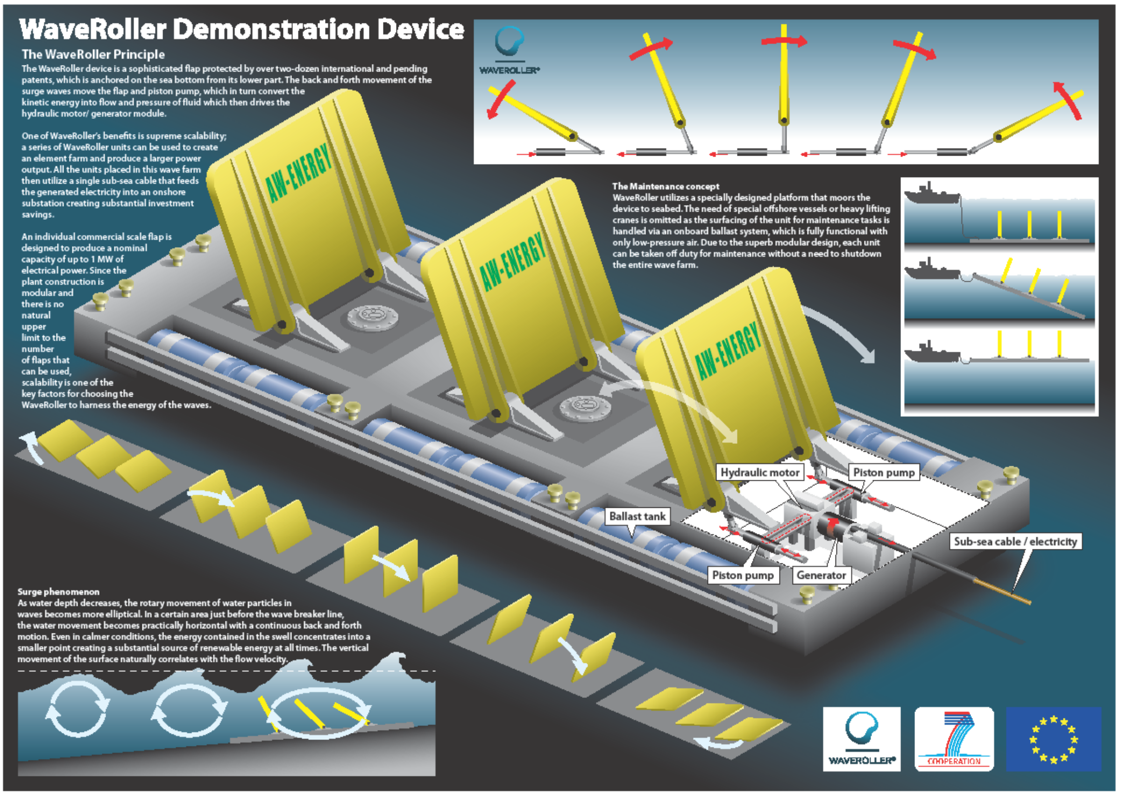
Therefore, in the chart below we exclude kW output for average steepness below 0.1 m/s.





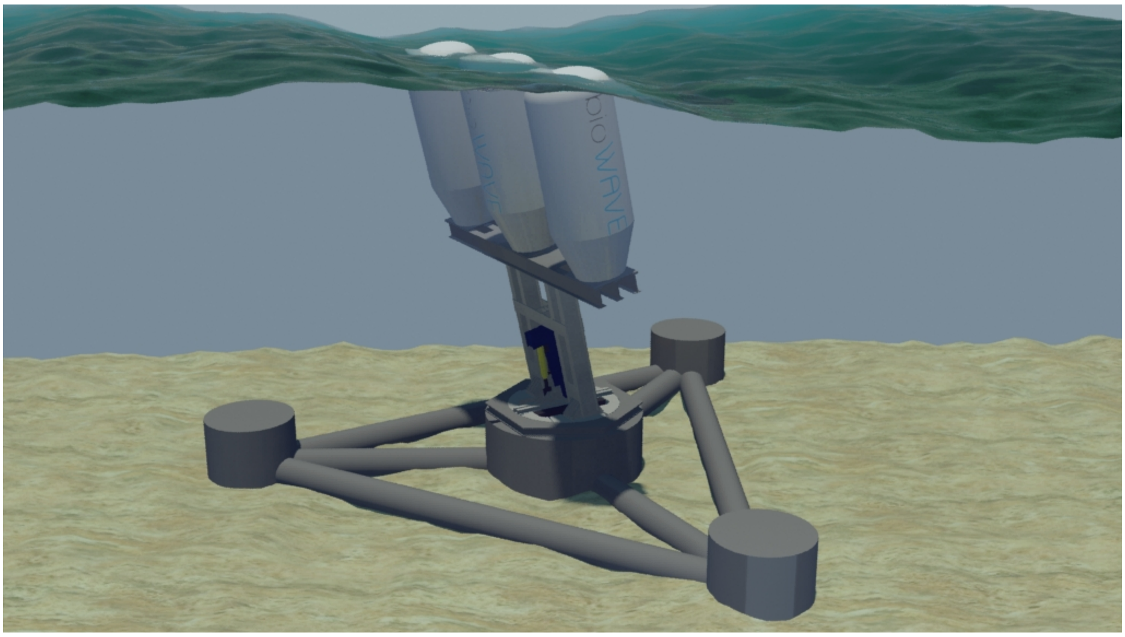
Company	AW-Energy Oy
Country	Finland
Web address	www.aw-energy.com
Technology Name	WaveRoller
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	C.
Features / Design principle	WaveRoller sits invisible on the seabed. All techic is inside the foundation under water, only electical cable come to the shore. Though, grid connection equipment are on shore
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL7 soon
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Many small units in the seawater 2001 - 2005, Prototype in Portugal in 2007 and 2008, power production 10 kW,
Next development steps	Grid connected demonstration unit into the water in April 2012.
Power take off	Hydraulic
Dimensions	26 m wide,12 high, 15 m long
Centerline device spacing for multiple devices (m)	50 m
Weight of super structure (ton)	100 t
Weight of power take off equipment (ton)	5 t
Min installation depth (m)	10 m
Max installation depth (m)	15 m
Design lifetime (years)	20 a
Rated power (kW) of commercial unit	500 kW
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	The efficiency of the hydraulic system is about 60 % (depends of operating point), so 500 kWe unit absorbs about 830 kW from the waves. Our flap is controlled all the time wave after wave control loops control the PTO every second and changes the controller output every second
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Simulations and teank tests

Estimated date commercially available	June 2015
Estimated production cost per rated unit (EUR)	3 Meur
Have environmental impact studies been performed	Yes
Discuss the survivability of the device and whether or not it has been tested.	There are no large waves (freaks) in the depth of 12 m, a flap moves with the wave, the system can be but put into free wheeling mode, if needed.
Technical publications	
Figures/photographs of device have been attached to reply	Yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	No



Note – The remainder of the details of the response from BioPower Systems Pty Ltd are not to be distributed to the general public.

Company	BioPower Systems Pty Ltd
Country	Australia
Web address	www.biopowersystems.com
Technology Name	bioWAVE
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	C
Rated power (kW) of commercial unit	1000



Company	Hann-Ocean Energy Pte Ltd
Country	Singapore
Web address	www.hann-ocean.com
Technology Name	Drakoo
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	G) Twin-Chamber Water Column
Features / Design principle	Drakoo is a patented twin-chamber wave energy convertor that captures both kinetic and potential water energy carried within incident ocean waves using non-return checkerboard valves and then converts this energy to electricity by a hydro-turbine. Single directional and continuous flow of water goes through the hydro-turbine during entire wave period and drives the linked permanent magnetic generator/alternator to produce stable electricity.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:20 scale model Darkoo-II was tested at NTU's wave flume in Aug-Sep 2010 for 5 days. Three 1:20 scale models were tested at Changi Beach of Singapore in 2009-2010. A full scale prototype was tested at Tuas View sea of Singapore in May 2011 for 14 days and Narec's 8m deep wave flume in July 2011 for 6 days.
Next development steps	We are conducting a 16kW Drakoo Type-B full scale prototyping supported by Singapore governmental grant followed by further developing a 96kW Drakoo wave farm at Tuas View sea of Singapore. The 1st prototype is expected to be deployed in July 2012 and the wave farm is expected to be completed in mid 2013.
Power take off	Kaplan hydro turbine with single/double regulated impeller
Dimensions	Drakoo Type-B: 3mx2.5mx2.5m (4kW); Drakoo Type-R: Dia22mx11m (1MW)
Centerline device spacing for multiple devices (m)	3/50
Weight of super structure (ton)	3.08/250
Weight of power take off equipment (ton)	0.12/5
Min installation depth (m)	1.35/12
Max installation depth (m)	300

Design lifetime (years)	20
Rated power (kW) of commercial unit	4/1000
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	See Power Output Scatter Diagrams projected based on Narec test results
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Narec wave flume tests
Estimated date commercially available	Sep 2012
Estimated production cost per rated unit (EUR)	20,000(4kW)/1,800,000(1MW)
Have environmental impact studies been performed	Yes
Discuss the survivability of the device and whether or not it has been tested.	A stress-relieving design allows the water to simply overtop into or overflow from the device. Drakoo therefore does not try to stand against the incident waves or to withhold high internal hydrostatic pressure. Additionally, Drakoo's structure makes use of unique flexible valves instead of mechanical hinges structure and is thereby less susceptible to breakdowns. The probability of breakdowns is further limited, as the many of the components integrated into the Drakoo system are readily available in the market and therefore have a track record of performance. Drakoo is designed as a modular system bringing together standard parts and subsystems from mature industries. Not the components used to build Drakoo are unique, but rather the combination. This allows for a tremendous reduction in cost, while at the same time ensuring a high quality standard. For instance, Drakoo's impeller is a turbine type that has been used in hydro power plants for decades. Its gearbox and generator mirror those used in wind turbines. Additionally, the negative impact of a breakdown, should it occur, is limited by Drakoo's Plug-n-Run concept. This concept allows the major components, such as the power take-off system and the Checkerboard Valves, to be replaced within a very short time span.
Technical publications	Conference paper in International Symposium on Low Carbon & Renewable Energy Technology 2011 in Korea
Figures/photographs of device have been attached to reply	Yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge,	Yes. Drakoo utilises a twin chamber principle and does not have any moving parts outside its body. The Drakoo 'box' can therefore simply be attached to

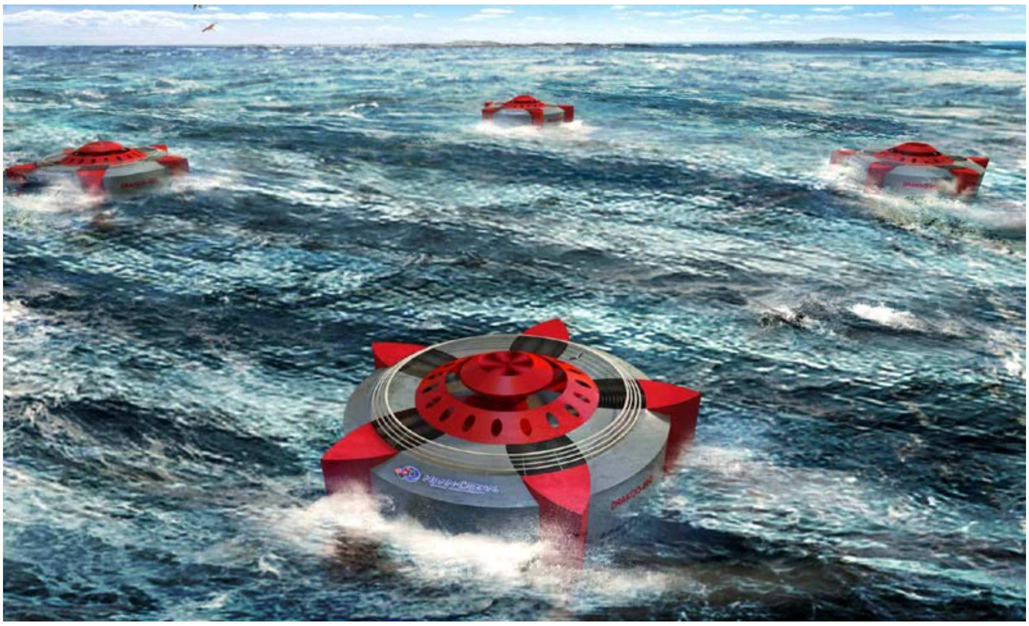
or submerged floating tunnel. If so, how?	other marine structures. Hann-Ocean is currently conducting a prototyping for total 75m floating jetty with 24 Drakoo Type-B cells (4kW each).

Technical Specification

Product Type	Type-B
Product Model No.	B0004
Dimensions	3m x 2.7m x 2.4m
Peak Power Output	4 kW
Gross Weight	3.2 t
Power Take-off System	Kaplan Turbine

Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p)

Wave Height Hs \ Period Tp	1	2	3	4	5	6	7	8	9
1.3	0	1.25	5.83	8.61	8.60	6.78	4.92	3.23	0
1.2	0	1.25	5.83	8.61	8.60	6.78	4.92	3.23	0
1.1	0	1.25	5.83	8.61	8.60	6.78	4.92	3.23	0
1	0	1.25	5.83	8.61	8.60	6.78	4.92	3.23	0
0.9	0	1.01	4.73	6.97	6.96	5.49	3.98	2.61	0
0.8	0	0.80	3.73	5.51	5.50	4.34	3.15	2.07	0
0.7	0	0.61	2.86	4.22	4.21	3.32	2.41	1.58	0
0.6	0	0.45	2.10	3.10	3.09	2.44	1.77	1.16	0
0.5	0	0.31	1.46	2.15	2.15	1.70	1.23	0.81	0
0.4	0	0.20	0.93	1.38	1.38	1.08	0.79	0.52	0
0.3	0	0.11	0.53	0.77	0.77	0.61	0.44	0.29	0
0.2	0	0.05	0.23	0.34	0.34	0.27	0.20	0.13	0
Capture Width Ratio (CWR)	0.0%	25.5%	79.6%	88.1%	70.4%	46.3%	28.8%	16.5%	0.0%



Company	MotorWave group
Country	Hong kong
Web address	www.motorwavegroup.com
Technology Name	MotorWave
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	G
Features / Design principle	MotorWave is composed of modules made of 2 floats.the up and down are transferred to a central shaft that combines ennergy of all modules.transformation is made by hydrolic converting into compressed air
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	1;1 scale model for 50cm wave was tested in HK harbor in 2005 1:1 scale for 20cm wave was tested in HKU lab in 2005,1:1 scale model for 1m wave was tested at sea in hong Kong in 2006
Next development steps	waiting for orders
Power take off	Hydrolic using sea water
Dimensions	each module is (for 2m) waves 6 m wide and 3 m long.the final length is between 90 to 300 m
Centerline device spacing for multiple devices (m)	1m
Weight of super structure (ton)	2
Weight of power take off equipment (ton)	1
Min installation depth (m)	floating
Max installation depth (m)	floating
Design lifetime (years)	50years or more
Rated power (kW) of commercial unit	16Kw per module for 2m wave .81Kw for 3m wave
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	N(number of modules)H(wave height)*4/P(period)
Source of wave energy absorption performance (numerical simulations or random wave model tests)	test in wave tank in university
Estimated date commercially available	6 month after order

Estimated production cost per rated unit (EUR)	for 2m wave approx 20 000 Euro per module. For 3m wave approx 30 000 Euro per module.for 5m
Have environmental impact studies been performed	NO
Discuss the survivability of the device and whether or not it has been tested.	the system is floating and design to take high energy wave
Technical publications	see our website
Figures/photographs of device have been attached to reply	
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Motorwave can be attached to any structure or anchor to any sea bed by cables

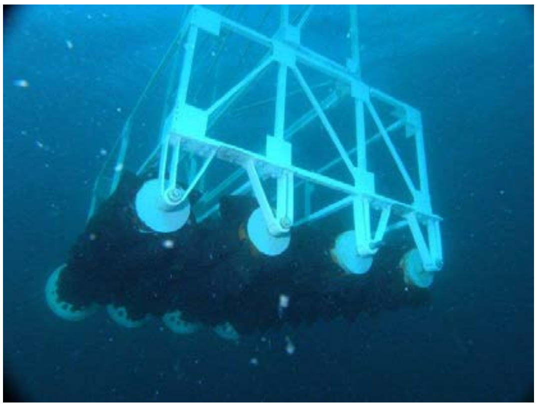
Source - www.motorwavegroup.com

Company	Ocean Energy Industries. Inc.
Country	USA
Web address	http://www.oceanenergyindustries.com
Technology Name	WaveSurfer
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B
Features / Design principle	WaveSurfer consists of two bodies, a buoyant body that floats on the surface of water and a submerged body suspended from the buoyant body. The submerged body consists of electric generators and horizontally-aligned rotors.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL9
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Full scale models are in commercial use for several years at locations around the world
Next development steps	Optimization
Power take off	Rotation
Dimensions	Variety of models and configurations. At least 5 basic models of different sizes.
Centerline device spacing for multiple devices (m)	Vary
Weight of super structure (ton)	Vary
Weight of power take off equipment (ton)	Vary
Min installation depth (m)	25
Max installation depth (m)	no strict max
Design lifetime (years)	Min 30
Rated power (kW) of commercial unit	From 0.5kW to 10MW
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	Vary
Source of wave energy absorption performance (numerical simulations or random wave model tests)	real life tests
Estimated date commercially available	2006
Estimated production cost per rated unit (EUR)	US $2,000 per kW capacity
Have environmental impact studies been performed	yes

Discuss the survivability of the device and whether or not it has been tested.	WaveSurfer's main power conversion and generation parts are completely submerged at a depth where water is not affected by the waves. No matter how significant is a wave action on the water surface, at the same time the water is calm at a depth of around one-half wavelength of the prevailing waves in the region. This design results in amazing survivability of each unit during extreme storms without any damage that would affect the unit's performance.
Technical publications	None
Figures/photographs of device have been attached to reply	None
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Can't be combined structurally. However the WaveSurfer device(s) can be installed in vicinity of the crossing if so required. Are there any waves in the fjord? Basically WaveSurfer is a deep, open water system.

POWER MATRIX					
Model	WS-1	WS-2	WS-3	WS-4	WS-5
Nominal Power Output (kW)	50	200	700	1100	2100
Max Power Output (kW)	120	370	1120	2500	6500
Wave height, m	POWER OUTPUT (kW)				
0.5	3	6	11	17	33
1	13	23	45	69	132
1.5	30	52	101	156	297
2	53	92	179	277	528
2.5	82	144	280	433	824
3	119	208	404	623	1187
3.5	162	283	549	848	1616
4	211	369	717	1108	2110
4.5	267	467	908	1402	2671
5	330	577	1121	1731	3297
5.5	399	698	1356	2094	3989
6	475	831	1614	2493	4748
6.5	557	975	1894	2925	5572
7	646	1131	2197	3393	6462
7.5	742	1298	2522	3895	7418
8	844	1477	2870	4431	8440
8.5	953	1667	3240	5002	9528
9	1068	1869	3632	5608	10682
9.5	1190	2083	4047	6249	11902
10	1319	2308	4484	6924	13188

Max Power Output is limited by standard generator capacity
Potential Power Output above standard generator capacity colored in orange

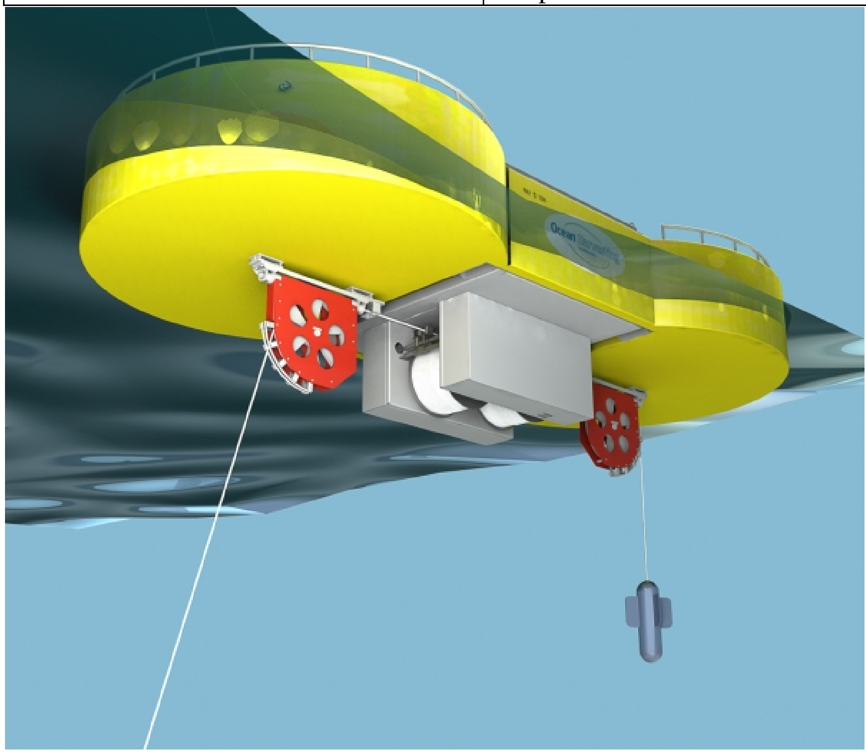


Source - http://www.oceanenergyindustries.com

Company	Ocean Harvesting Technologies AB
Country	Sweden
Web address	www.oceanharvesting.com
Technology Name	Ocean Harvester
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B
Features / Design principle	The Ocean Harvester captures energy from the rise of each wave with the use of a winch system, which provides sufficient length of stroke for the largest wave on the selected site. A patented mechanical PTO with a counterweight efficiently converts the highly fluctuating energy that is absorbed from the waves into a smooth power and force through system. This way the PTO and power electronics can be sized for the average energy instead of the peak energy. The key advantage with this is considerable reduction in the cost of the PTO, as well as high efficiency and load factor of the generator and power electronics, all together resulting in low cost of energy.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 4, design of 1/2 model of a 100 kW unit is completed, manufacturing will start in may 2012.
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Several scale 1:40 tests of simplified models have been performed in a water laboratory at DHI in Hörsholm Denmark 2009 - 2011. A 1:10 scale prototype of the PTO and control system has been tested in a test rig setup running irregular waves. Power smoothing capabilities has been demonstrated with very promising results. Karlskrona Sweden 2009-2011. A 1:2 Scale sea trial model design of the Ocean Harvester is completed.
Next development steps	Manufacturing of the 1:2 scale model will start in Q2 2012 and sea trials is planned in 2013 at Risör in co-operation with Fobox AS / Fred Olsen Ltd. The design work for scaling up the system to full scale (100 kW) will be started in Q3 2012.
Power take off	Patented mechanical PTO using a counterweight for powersmoothing.

Dimensions	The buoy of the 1:2 scale model is 12x5,6x1,4 (LWH). The estimated size of the full scale model is thus 24x11,2x2,8 (LWH).
Centerline device spacing for multiple devices (m)	Approx. 50
Weight of super structure (ton)	Approx. 85
Weight of power take off equipment (ton)	Approx. 25
Min installation depth (m)	Approx. 20
Max installation depth (m)	Approx. 100
Design lifetime (years)	20
Rated power (kW) of commercial unit	Approx. 100-150
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	An unlimited power matrix has been provided in the wave performance tab. The device rated power is selected close to the most frequent sea state at the installation site rather than less frequent and more energetic sea state. This is done in order to increase the electrical efficiency and load factor of the power electronics, as well as reducing the cost of power electronics and cabling. The device rated power can be maintained in stronger sea states with the use of a clutch that operates in a way that limits the energy capture. It should be noted that one of the main challenges with wave power is to achive high efficiency in the process of converting the highly fluctuating energy absorbed from the wave motion into electricity. Numerical modeling of the Ocean Harvester efficiency have been done and shows that approx. 75% mechanical efficiency, 90% electrical efficiency and 60% load factor as an annual average on a site with good wave conditions. Please provide wave data for a more detailed analysis of the device performance at the intended installation site.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Numerical simulations and random wave model tests.
Estimated date commercially available	2016
Estimated production cost per rated unit (EUR)	Levelized cost of Energy presented as a learning curve included in the attached presentation.
Have environmental impact studies been performed	No

Discuss the survivability of the device and whether or not it has been tested.	Winch systems reduce structural strain (end limits are never reached). The counterweight limits the mechanical peak loads/torque in the system in all wave conditions. The Power take-off can be disengaged to put the wave energy converter in standby/failsafe mode to survive the roughest sea states. Position moorings (secondary moorings) are used to keep the position.
Technical publications	
Figures/photographs of device have been attached to reply	Yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Mentioned submerged structures could be used as anchoring points for standalone units, reducing the cost of anchoring for the WEC array installation. The PTO solution developed by OHT could also be integrated into structures near the surface. This could make possible energy absorption in both rising and descending wave, which is an advantage compared to a stand-alone unit that only absorbs energy in the rising wave. OHT is open for discussion regarding both stand-alone units and integration of the WEC system into support structures located near the surface. We need more information about the structures in order to present how this could be done in more detail.



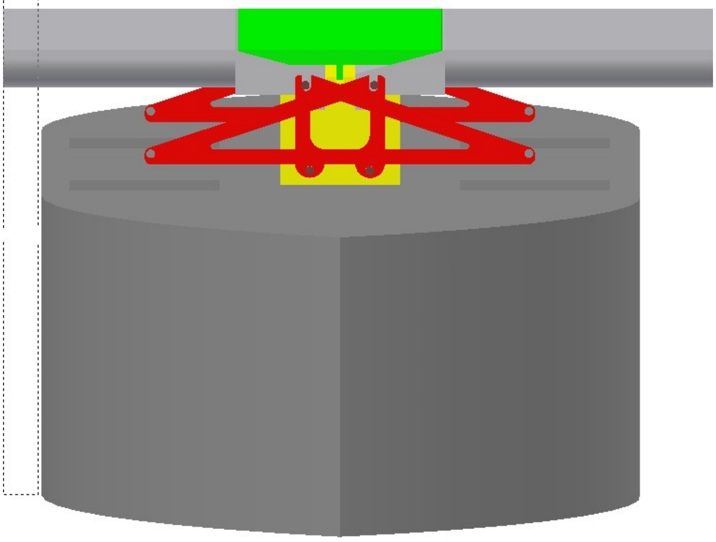
Source - www.oceanharvesting.com

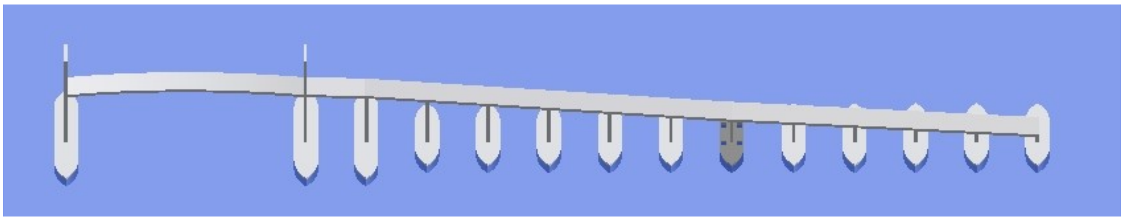
Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p)

H_s (m) \ T_p (s)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
10	869	814	749	665	576	509	452	407	370	339	313	291	271	255	240	226	214	204
9.5	822	770	709	629	545	481	428	385	350	321	296	275	257	241	227	214	203	193
9	775	726	668	593	514	454	404	363	330	303	279	259	242	227	214	202	191	182
8.5	728	682	628	557	482	426	379	341	310	284	262	244	227	213	201	190	180	171
8	681	638	587	521	451	399	355	319	290	266	245	228	213	199	188	177	168	160
7.5	634	594	547	485	420	371	330	297	270	248	229	212	198	186	175	165	156	149
7	587	550	506	449	389	344	306	275	250	229	212	196	183	172	162	153	145	138
6.5	540	506	465	413	358	316	281	253	230	211	195	181	169	158	149	141	133	126
6	493	462	425	377	327	289	257	231	210	192	178	165	154	144	136	128	122	115
5.5	446	418	384	341	295	261	232	209	190	174	161	149	139	131	123	116	110	104
5	399	374	344	305	264	234	208	187	170	156	144	133	125	117	110	104	98	93
4.5	352	330	303	269	233	206	183	165	150	137	127	118	110	103	97	92	87	82
4	305	286	263	233	202	179	159	143	130	119	110	102	95	89	84	79	75	71
3.5	258	242	222	197	171	151	134	121	110	101	93	86	81	75	71	67	64	60
3	211	198	182	161	140	123	110	99	90	82	76	71	66	62	58	55	52	49
2.5	164	153	141	125	109	96	85	77	70	64	59	55	51	48	45	43	40	38
2	117	109	101	89	77	68	61	55	50	46	42	39	36	34	32	30	29	27
1.5	70	65	60	53	46	41	36	33	30	27	25	23	22	20	19	18	17	16
1	23	21	20	17	15	13	12	11	10	9	8	8	7	7	6	6	6	5
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Company	OWWE - INNOVAKO
Country	Norway
Web address	www.owwe.net
Technology Name	Floating Bridge
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	
Features / Design principle	INNOVAKO has a floating bridge concept which can be of interest for Norwegian authorities. A flexible joint can solve the problems of long distance floating bridges. In principle there is no limit in length and the problem to solve is how long the sections between the flexible joints can be. In addition to the flexible joint the bridge are anchored in the same way as floating quays. If a floating bridge moves sideways the flexible joint open at one of the sides and the force to keep the bridge straight increase. From 0 to 160 tons (the joint shown) when the flexible joint open to its maximum of 1 m, which means an angle of 2.5 degrees. Perhaps it is favorable to start with some stretch.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 1
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	
Next development steps	
Power take off	
Dimensions	
Centerline device spacing for multiple devices (m)	
Weight of super structure (ton)	
Weight of power take off equipment (ton)	
Min installation depth (m)	
Max installation depth (m)	Swell is a bigger problem than depth.
Design lifetime (years)	Concrete can stay at sea for a long time and quality of the concrete decides how long.
Rated power (kW) of commercial unit	

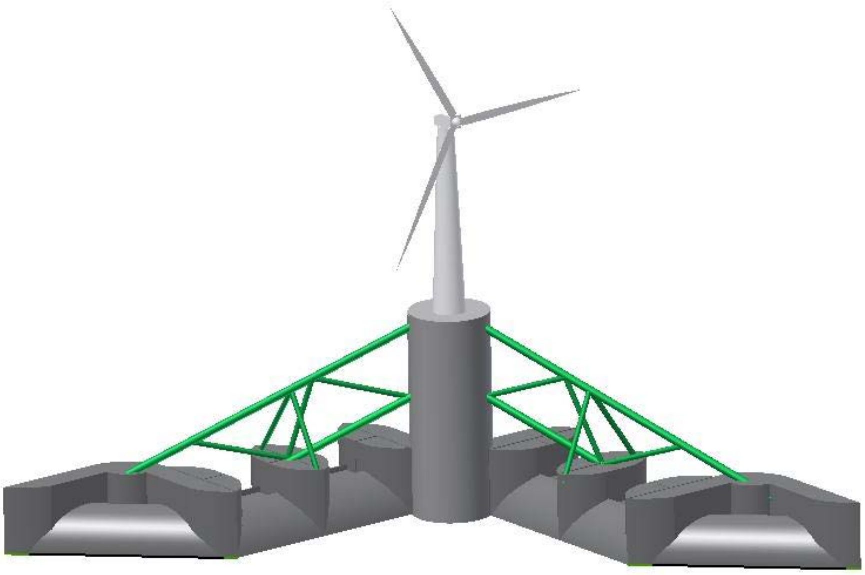
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	
Source of wave energy absorption performance (numerical simulations or random wave model tests)	
Estimated date commercially available	
Estimated production cost per rated unit (EUR)	
Have environmental impact studies been performed	
Discuss the survivability of the device and whether or not it has been tested.	
Technical publications	
Figures/photographs of device have been attached to reply	2 figures (jpg) is attached.
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	





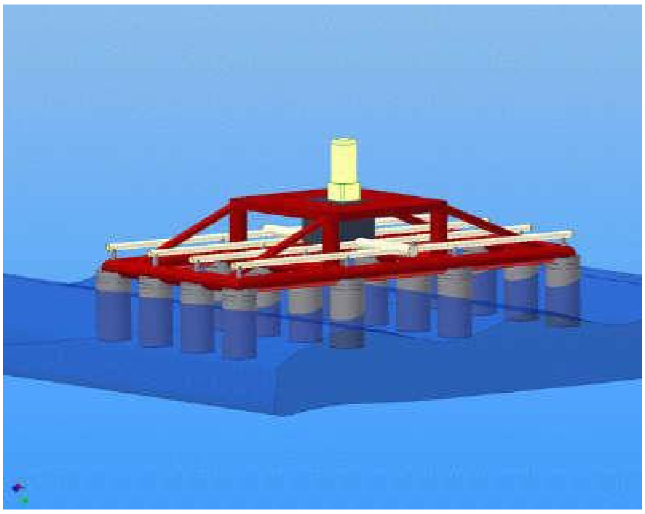
Company	OWWE - INNOVAKO
Country	Norway
Web address	www.owwe.net
Technology Name	OWWE-Rig
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	E
Features / Design principle	The main structure is a float with several basins. The float can be trimmed and the height above sea desired the water pressure at the turbines. OWWE-Rig can be equipped with hinged walls to make it more efficient. OWWE-Rig is constructed as a hybrid wind and wave energy converter. The wind-turbines are of the type in normal use.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 2
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:20 scale model was made in 2005. The model has not been tested, due to lack of founding.
Next development steps	In search for funding the company participates at conferences, and the next is the wave energy conference in Dublin 17th to 19th of October.
Power take off	Low head turbines normally used in hydro electric power plants.
Dimensions	The wave conditions will desired the dimensions, and as a first step INNOVAKO seek founding for a North Sea Demonstrator of 110m.
Centerline device spacing for multiple devices (m)	Multiple OWWE-Rigs will be placed along a line(50 km from coast)
Weight of super structure (ton)	Not calculated
Weight of power take off equipment (ton)	Not calculated
Min installation depth (m)	20m
Max installation depth (m)	No limit
Design lifetime (years)	If concrete can be used as construction material it can be at sea for a long period, depending on the quality of the concrete.
Rated power (kW) of commercial unit	5000(North Sea Demonstrator)
Wave energy absorption performance (kW) (before losses in conversion to	North Sea Demonstrator in 30 kW/m wave climate and 1 MW wind turbine and 0,3 power take of: 1300

electric power) as a function of significant wave height and peak wave period ****	kW
Source of wave energy absorption performance (numerical simulations or random wave model tests)	No data
Estimated date commercially available	Depends on founding.
Estimated production cost per rated unit (EUR)	6.00E+06
Have environmental impact studies been performed	No
Discuss the survivability of the device and whether or not it has been tested.	The main target for the North Sea Demonstrator is testing of survivability. OWWE-Rig is an overtopping technology as Wave Dragon. Wave Dragon has been tested as a 1 : 4,5 prototype in sea condition with good results.
Technical publications	www.owwe.net
Figures/photographs of device have been attached to reply	Abstract sent for the Dublin conference in October is attached (pdf).
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	The force in waves is a problem for floating bridges and should therefore be placed at places with no swell. In fjords the wind climate is not the best and therefore INNOVAKO is not in favor of combining either wave or wind technology with floating bridges. INNOVAKO has a floating bridge concept where a flexible joint is the key element. I therefore attached papers showing INNOVAKO`s floating bridge.



Company	OWWE - INNOVAKO
Country	Norway
Web address	www.owwe.net
Technology Name	Wave Pump-Rig
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B
Features / Design principle	Wave Pump-Rig is a pneumatically stabilized float with 16 cylinders open to the sea. 12 of the cylinders house a wave pump which pumps seawater to a reservoir where the turbine is placed. The cylinder in each corner is for stabilization purposes.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 2
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	No scale model has been built and no tests have been done.
Next development steps	In search for funding the company participates at conferences, and the next is the wave energy conference in Dublin 17th to 19th of October.
Power take off	Turbines normally used in hydro electric power plants.

Dimensions	The wave conditions will determine the dimensions.
Centerline device spacing for multiple devices (m)	Multiple Wave Pump-Rigs can be placed along the coastline or at open sea.
Weight of super structure (ton)	Not calculated
Weight of power take off equipment (ton)	Not calculated
Min installation depth (m)	20m
Max installation depth (m)	No limit
Design lifetime (years)	Not calculated
Rated power (kW) of commercial unit	Depends of sea climate and the size of the rig built.
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	Not calculated
Source of wave energy absorption performance (numerical simulations or random wave model tests)	No data
Estimated date commercially available	Depends on founding
Estimated production cost per rated unit (EUR)	Not calculated
Have environmental impact studies been performed	No
Discuss the survivability of the device and whether or not it has been tested.	Air moves freely inside a pneumatically stabilized platform and big waves will therefore have less impact at the construction than an ordinary floats. Active wave pumps decide the impact. Each corner must have a unit with sufficient bouncy for stabilizing the rig.
Technical publications	www.owwe.net
Figures/photographs of device have been attached to reply	Abstract sent for the Dublin conference in October is attached (pdf).
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	The force in waves is a problem for floating bridges and should therefore be at a place with no swell. INNOVAKO is not in favor of combining either wave or wind technology with floating bridges. INNOVAKO has a floating bridge concept where a flexible joint is the key element. I therefore attached papers showing INNOVAKO`s floating bridge.



Company	OWECO Ocean Wave Energy Company
Country	USA
Web address	http://www.owec.com
Technology Name	OWEC® Ocean Wave Energy Converter
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B
Features / Design principle	Any number of self-referencing, scalable modules form submerged open truss arrays permitting wave regeneration there between. Reciprocation of modules' three large buoys/drive shafts counter-rotate generator components to increase relative speed/electrical output. Several quick-connected modules' output is additively combined and terminates at load. Arrays provide high module/mooring ratio.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 5/6; new PTO: TRL 3/4
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Three modules produced 4 hours electricity during 1982-05 tank tests at MIT, Cambridge, MA, USA. One smallest, full scale (for 1m wave H) linear/rotary converter and flywheel generator produced 3 days electricity during 1990-05 "breadboard" tests at OWECO facility, Pawtucket, RI, USA. Scaled experiments/virtualization are completed and planned at the OWECO facility in Portsmouth, RI, USA.
Next development steps	Construct, and test experimental CR counter rotating generators, adjustable ballast, and sensor control system. Construct and test 6 or 10 connected modules in waves to SS5.
Power take off	Direct drive linear/rotary converter additively combines buoyancy/gravity forces in counter rotating generators. Proprioceptive PTO control is managed via multi-module sensor inputs.

Dimensions	Excluding largest modules for sea state 9, three sizes are scaled correspondent to regional average annual maximum sea state- significant wave height. Further power detail is required for CR generator. OWEC® size 1 2 3 Sea State (SWH) 0-4 5-6 7-8 Width 5.5 10.9 21.9 Height 7.9 15.8 31.7
Centerline device spacing for multiple devices (m)	5.51 10.93 22
Weight of super structure (ton)	TBD- variable accordant with materials
Weight of power take off equipment (ton)	TBD- variable accordant with materials
Min installation depth (m)	15
Max installation depth (m)	6400
Design lifetime (years)	20-30/module. Unlimited for arrays via scheduled module service/replacement swap.
Rated power (kW) of commercial unit	1 2 3 average/module 30 250 2150
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	See below
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Numerical simulations partially based on tests
Estimated date commercially available	
Estimated production cost per rated unit (EUR)	
Have environmental impact studies been performed	Yes (empirical). Detailed study required.
Discuss the survivability of the device and whether or not it has been tested.	The device is equipped with a remote operated survival system. When a storm is approaching, the device automatically will detect that it should go into survival mode and portions will be filled with water so that they more deeply submerge until the storm has passed. Other portions will be electronically locked in extended positions that assist flotation of the device, at greater depth, while also prohibiting catastrophic sinking.
Technical publications	Numerous general readership publications beginning 1981. Infra-academic engineering reports published at various France universities, 2002 - 2006.

Figures/photographs of device have been attached to reply	No. Images/descriptions available via web address.
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	While this device is best suited for offshore applications, it may be linearly deployed as breakwater adjacent to crossing structure.

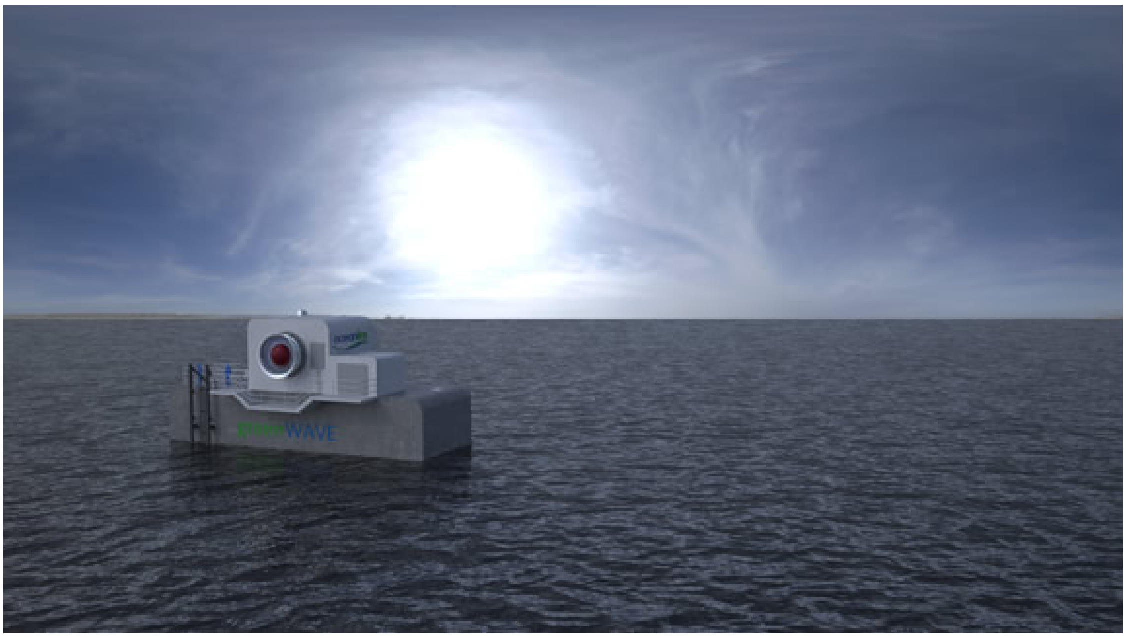
Source - http://www.owec.com

Theoretical wave energy conversion absorption performance (kW) of one OWEC® size 2 module as function of significant wave height (H_s) and peak wave period (T_p).
Typical three module OWEC® triads produce triple as shown.

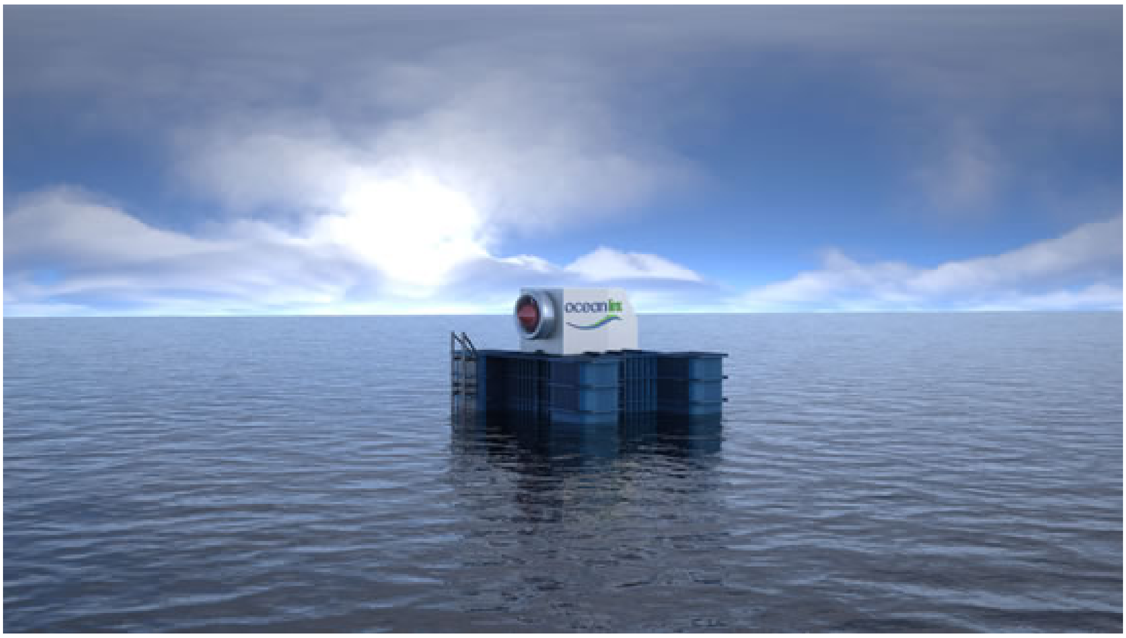
H_s (m) \ T_p (s)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	318	297	279	262	249	234	223
6.5	0	0	0	0	0	0	0	0	0	0	298	277	258	242	227	214	204	195
6	0	0	0	0	0	0	0	0	0	298	275	255	240	223	213	198	187	180
5.5	0	0	0	0	0	0	0	0	297	272	249	233	218	204	194	181	172	165
5	0	0	0	0	0	0	0	300	272	249	231	214	200	187	177	167	157	150
4.5	0	0	0	0	0	0	299	269	243	223	205	192	179	167	157	149	141	134
4	0	0	0	0	0	298	264	238	216	198	183	173	159	149	141	132	126	120
3.5	0	0	0	0	299	263	231	208	189	173	160	150	139	130	123	116	110	104
3	0	0	0	298	255	223	198	180	162	150	137	128	120	112	105	100	94	89
2.5	0	0	294	246	210	184	165	147	134	123	113	105	98	92	87	82	78	74
2	0	297	239	198	170	148	132	119	108	99	92	85	79	75	70	66	63	59
1.5	297	222	178	149	127	111	99	89	81	75	69	64	60	55	53	50	47	45
1	194	145	127	96	83	74	65	58	53	49	45	42	39	37	34	31	30	29
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Company	Oceanlinx Ltd
Country	Australia
Web address	www.oceanlinx.com
Technology Name	greenWAVE/ogWAVE/blueWAVE
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	D
Features / Design principle	greenWAVE is a bottom mounted 1MW device. ogWAVE is a floating deepwater 500kW single chamber device, blueWAVE is a large deepwater floating with rated capacity of our 2.5 MW device.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Oceanlinx have been using the Australian Maritime College, Southampton UK and other global facilities for over 10 years to conduct trials at their large wave tank facilities.
Next development steps	Commercial projects in Australia, Hawaii and Portugal
Power take off	airWAVE turbine
Dimensions	greenWAVE 20m x 20m x20m, ogWAVE 16m x 19m x 18m, blueWAVE 100m x 35m x 20m (Approx.)
Centerline device spacing for multiple devices (m)	varies, site specific
Weight of super structure (ton)	greenWAVE 2000t, ogWAVE 350t, blueWAVE 2000t (Approx.)
Weight of power take off equipment (ton)	35
Min installation depth (m)	greenWAVE 10m, ogWAVE & blueWAVE 40m
Max installation depth (m)	greenWAVE 15m, ogWAVE & blueWAVE 200m
Design lifetime (years)	25
Rated power (kW) of commercial unit	greenWAVE 1000kW, ogWAVE 500kW, blueWAVE 2500kW
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	Commercially sensitive
Source of wave energy absorption performance (numerical simulations	Numerical simulations & random wave model tests

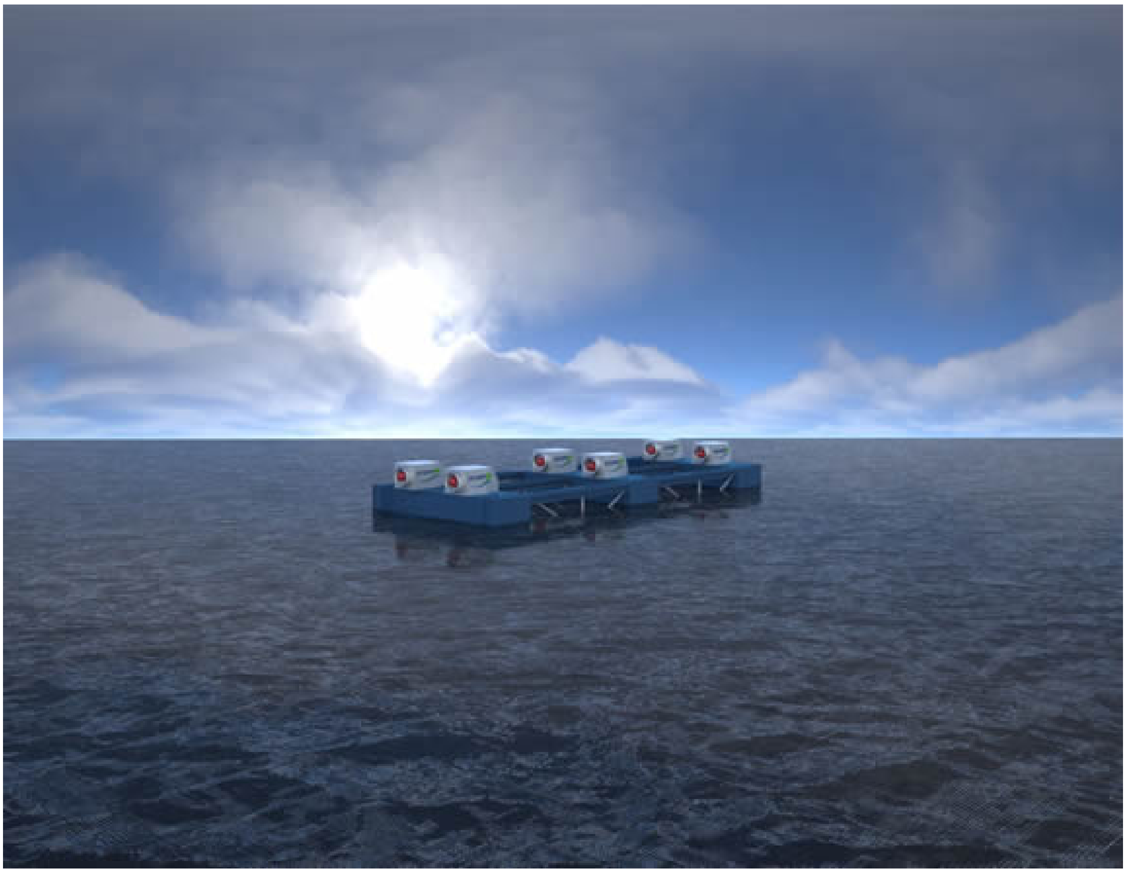
or random wave model tests)	
Estimated date commercially available	2012
Estimated production cost per rated unit (EUR)	Commercially sensitive
Have environmental impact studies been performed	Extensive environmental monitoring will be conducted during the first commercial project
Discuss the survivability of the device and whether or not it has been tested.	all devices are designed and tested in full size or scaled trials to design wave
Technical publications	
Figures/photographs of device have been attached to reply	see email attachments
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	The greenWAVE device can be incorporated into the structure much like it would be incorporated into a breakwater.



Source - www.oceanlinx.com



Source - www.oceanlinx.com



Source - www.oceanlinx.com

Company	Perpetuwave Power Pty Ltd
Country	Australia
Web address	www.perpetuwavepower.com
Technology Name	Wave Harvester
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	A,B
Features / Design principle	The Perpetuwave Wave Harvester technology is based on a floating platform, with the elongated Hybrid Float design incorporated beneath the deck. The Hybrid elongated floats operate from trailing arms offering the most robust and light weight design possible. The key technical benefits of the Hybrid float design are, • The elongated floats are rectangular in shape with the long side being parallel to the wave fronts. This offers the highest possible buoyancy loading possible as the length of the float is immersed in a wave front at once and is then moved up over the wave. This design also offers the lightest weight floats possible with a working buoyancy load to float/ trailing arm weight ratio of 4:1, which is much higher than any other design can offer. • The angular motion of the floats offered by the trailing lever arm is in the direction of wave travel as well as upwards. This also captures the substantial horizontal directional component of the wave energy (the direction of wave travel) as well as the typically converted vertical energy component. Extracting the horizontal directional energy component also minimises wave reflection, reduces impact loads of breaking waves on to the floats and structure, and allows a series of floats to be placed one behind another in a commercially viable array. • The trailing lever arm design which the floats are attached, and move from is by far the most robust design available. The specific design criteria is are similar to the case of a wheel of a moving vehicle that hits a pot hole. It is no coincidence then that nearly all vehicle suspension systems around the world use a similar trailing arm system. It is the most robust design possible.

	• The elongated floats easily extend wider to capture more energy in the same vein as wind turbines increase blade length to increase capacity, with no extra componentry required.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 6 completed, 7/8 planned
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1/3 scale proof of concept prototype was tested in the ocean off of Redcliffe between September 2005 and January 2009. The prototype included a complete direct drivetrain and generator so real performance (electricity produced) could be accurately measured. In first testing the prototype proved actual electricity production to be slightly below expectations but considering the state of the development at the time, was extremely encouraging. A 60 % increase in electricity production was achieved over the course of the testing campaign with a number of improvements being trialled during the period. A 1/8 scale model was tested in a wave tank at The University of Queensland between April and June of 2010. Again a high level of authentication was sought with a complete direct drivetrain and generator installed so real performance (electricity produced) could be accurately measured and averaged over a window of time for average electricity production. A number of further improvements were trialled during the programme with a doubling of electricity production being achieved by the end of the of the test program. At the end of the test programme average electricity production readings of between 20% & 40% extraction/ conversion efficiency were recorded over a range of wave height conditions.
Next development steps	The next stage in our development commercialisation pathway is to develop and test a 20kW Pilot Demonstration version of our Wave Harvester technology in the open ocean. The main outcomes of this are to; • Authenticate the performance projections for commercially sized units operating in the real case environment of the open ocean which is expected to move the credibility of the technology towards bankable feasibility status. • Manage the technical risk of the larger Stage 4 commercial demonstration vessel by using a stepping stone incremental increase in the size of the Wave Harvester units. Feedback from the smaller

	version will be designed into the larger unit to ensure full risk management of this process.
Power take off	direct drive system, all components housed in a sealed environment for low O&M costs.
Dimensions	An 850kW unit will be approximately 40m wide
Centerline device spacing for multiple devices (m)	100m apart for singluar units, if the units are placed side by side for a floating bridge design would make them 40m apart
Weight of super structure (ton)	580 ton
Weight of power take off equipment (ton)	100 ton
Min installation depth (m)	5m
Max installation depth (m)	yet to be determined, but using the experience of the offshore oil and gas platforms, this could be thousands of metres.
Design lifetime (years)	30
Rated power (kW) of commercial unit	850kW before a 1,500kW unit is developed
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	Initial numerical simulations were based on force over distance theory as this was considered to be much more accurate than other forms of wave theory which have historically been shown to be very inaccurate in predicting electricity produced. This is eveidenced in the EPRI reports that investigate both the Pelamis and Energetec designs.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Our wave energy absorption performance is based on actual mean electricity production over a window of time to establish real conversion efficiency.
Estimated date commercially available	Jul-15
Estimated production cost per rated unit (EUR)	$Euro 4.5M
Have environmental impact studies been performed	No, planned for the next stage of development

Discuss the survivability of the device and whether or not it has been tested.	The Perpetuwave Wave Harvester technology is based on a floating platform which has proved to be be one of the most survivable designs known due to the extensive history and experience of the offshore oil and gas indsutry. A 1/4 scale prototype has been extensively tested in severe storm conditions in the ocean in Moreton Bay, Queensland Australia. The unit operated perfectly. A survival mode is planned to be tested in the next stage of development which will raise the floats from the water and for them to be secured fast against the upper deck. Minimal frontal area, and minimal wave impact area of the floating platform design are key features that the design the most survival design ever produced.
Technical publications	Report prepared by Uniquest for The University of Queensland titled 'Tank Testing of the Perpetuwave Wave Harvester technology' by Associate Professor Tom Baldock.
Figures/photographs of device have been attached to reply	please see attached
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Yes, it is very possible to combine the device with a fjord crossing that implements a floating bridge or submerged tunnel, but not for a suspension bridge unless the suspension bridge was positioned much closer to the water than convenional suspension bridges to minimuise exaggeration of forces tha occur with having an excessive radius arm(height of the bridge above the water). In the case of the floating bridge, the energy extraction floats would be operated from the underside of the bridge, in the same manner as we have currently developed the technology to operate from the underside of the platform. In the case of a submerged floating tunnel the floating platform design would offer the buoyancy for the tunnel if required.

Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p)

H_s (m) \ T_p (s)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10																		
9.5																		
9																		
8.5																		
8																		
7.5																		
7																		
6.5																		
6																		
5.5																		
5																		
4.5																		
4																		
3.5																		
3	90.72	169.344	211.68	254.016	296.352	338.688	381.024	423.36	465.696	435.456	471.744	423.36	453.6	387.072	411.264	326.592	344.736	241.92
2.5	63	117.6	147	176.4	205.8	235.2	264.6	294	323.4	302.4	327.6	294	315	268.8	285.6	226.8	239.4	168
2	40.32	75.264	94.08	112.896	131.712	150.528	169.344	188.16	206.976	225.792	209.664	188.16	201.6	172.032	182.784	145.152	153.216	107.52
1.5	22.68	42.336	52.92	63.504	74.088	84.672	95.256	105.84	116.424	127.008	117.936	105.84	113.4	96.768	102.816	81.648	86.184	60.48
1		18.816	23.52	28.224	32.928	37.632	42.336	47.04	51.744	56.448	52.416	47.04	50.4	43.008	45.696	36.288	38.304	26.88
0.5		4.704	5.88	7.056	8.232	9.408	10.584	11.76	12.936	14.112	13.104	11.76	17.64	10.752	11.424	9.072	9.576	6.72
0.125																		

The projected values of converted electricity are shown in the table above. The cut off after 3m is based on a floating bridge design. Electricity is expected to be normally produced past 5m wave height but this requires automation equipment that would not be suited to a floating bridge design.

Company	RESEN ENERGY
Country	Denmark
Web address	www.Resen.dk and www.ResenWaves.com
Technology Name	LOPF wave energy buoys
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B
Features / Design principle	The Lever Operated Pivoting Float LOPF buoy is characterised by low weight, simple design with few moving parts, direct electric drive output, unique pivoting float action which streamlines the float during storms when there is excessive pull in the mooring line and which limits the mooring line forces. --Not the least, the LOPF buoys are already commercial in small scale because it is affordable. +10 buoys have been sold already. Small buoys can be ordered today with a lead time of 5 months.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8 of small commercial 2 and 5 kW grid conected buoys
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Scale 1:25 fully instrumented LOPF buoy with power take off and measurement of mechanical and electric production in real time in North Sea wave conditions of 16 kW/m was tested at Aalborg University in December 2011. Grid connected 2 and 5 kW buoys are available for open sea operation during 2012. A full scale LOPF buoy of 300 kW for North Sea Operation in 16 kW/m with 720.000 kWh/y (with 60% electric conversion efficiency)will be available in 2014 -15, depending on customer demand. 10 to 50 kW LOPF buoys are expected to be available in 2013. The activity will grow organically depending on customer demand.
Next development steps	We have test sites in Øresund and Nissum Bredning and planned North Sea site in Hanstholm for late 2012
Power take off	Direct electric drive -No hydraulics
Dimensions	Full scale 300 kw buoy for North Sea is 15m x 20m x 2
Centerline device spacing for multiple devices (m)	60 m , depends on actual water depth
Weight of super structure (ton)	50 to 80

Weight of power take off equipment (ton)	10
Min installation depth (m)	20 m
Max installation depth (m)	100 m, depends on weight of mooring line
Design lifetime (years)	20
Rated power (kW) of commercial unit	300 kW for North Sea
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	30% effiency measured in scale 1:25. Good absorption in regular as well as irregular waves
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Both. Absorption efficiency is only used as a guide line. We are manily focused on wave to electric efficiency.
Estimated date commercially available	Available now as small 2 and 5 kW units for open sea operation
Estimated production cost per rated unit (EUR)	1,1 million €
Have environmental impact studies been performed	Yes, and also based on 3 years of sea operation
Discuss the survivability of the device and whether or not it has been tested.	The very nature of the Lever Operated Pivoting Float LOPF buoy concept was developed by trial and error tests of small buoy models in the sea. First after test model # 55 the test buoy survived storms and the LOPF concept was born. The key feature, which is also covered by patents in many countries, is that the taut moored buoy can pivot and streamline it self if exposed to big forces from waves. The system also produces electricity during storms. - During 2012 we will operate 2 and 5 kW buoys in the open sea and our goal is to ruggedise and make real time measurements on the buoys. When the reliabilty is as expected we will use this experience in the future designs of bigger buoys. The 2 and 5 kW systems will be sold in quantities of hundreds and will build up a big knowledge base.
Technical publications	Wave Power Lever Operated Pivoting Float LOPF study from Aaalborg University will be available shortly
Figures/photographs of device have been attached to reply	Yes and early day video can be found on YouTube
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Yes. We can imagine different ways of how the buoys can be integrated with floating structures. The lever arm is attached directly to the floating structure instead of a mooring line. For submerged tunnels the mooring line is attched to the tunnel and feeds electricity into the tunnel. - Details have to be discussed


Resen Waves
WAVE ENERGY MADE SIMPLE
Tel: +45 3940 4696 · info@resen.dk
www.Resen.dk · www.ResenWaves.com

Company	Resolute Marine Energy, Inc.
Country	USA
Web address	www.resolutemarine.com
Technology Name	SurgeWEC™
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	C
Features / Design principle	Bottom-mounted hinged flap.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 6
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A scale-model prototype was tested in the BOEM wave tank (Ohmsett) June 2011. A scale-model prototype was tested in the ocean at Jennette's Pier in North Carolina in December 2011.
Next development steps	We are planning two more rounds of ocean trials, both involving a full-scale prototype, in 2012. The latter of the two trials will incorporate the power takeoff system we have been developing in parallel.
Power take off	Hydraulic using bio-degradeable hydraulic fluid
Dimensions	The paddle of the full-sized SurgeWEC will be roughly 4m wide by 3m high.
Centerline device spacing for multiple devices (m)	N.A.
Weight of super structure (ton)	The tested prototype was appriximately 2 tons including ballast.
Weight of power take off equipment (ton)	Not known.
Min installation depth (m)	For full-scale device - preferrably no less than 5 meters
Max installation depth (m)	For full-scale device - preferrably no more than 8 meters
Design lifetime (years)	20
Rated power (kW) of commercial unit	30
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	Tests have shown an average of 40% at 80% water column coverage.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Wave tank tests.
Estimated date commercially	2013

available	
Estimated production cost per rated unit (EUR)	We're estimating about $5,000/kW for first commercial prototype trending downwards as manufacturing at scale begins.
Have environmental impact studies been performed	Not yet - but are planned for next round of ocean trials.
Discuss the survivability of the device and whether or not it has been tested.	Survivability has not been specifically tested yet but it is important to note that bottom-mounted OWSC are not subject to loading conditions present at the surface. In addition, to a degree not yet tested, OWSC naturally shed excessive energy when the angular displacement of the paddle becomes extreme.
Technical publications	We have not published results as yet other than in our quarterly reports to the U.S. Department of Energy
Figures/photographs of device have been attached to reply	Yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	SurgeWEC is designed to be bottom-mounted which means: a) it is not dependant upon another structure for stability; and b) it is designed to be deployed near-shore in shallow water (it is actuated by shallow-water waves) . Conversely, since it is fully submerged, SurgeWEC has no effect on view sheds.

Company	Sea Power Ltd.
Country	Ireland
Web address	www.seapower.ie
Technology Name	Sea Power Platform
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	A) Attenuator
Features / Design principle	The Sea Power Platform consists of 2 pontoons - Forward and Main Pontoon. The Main pontoon consists of two floats joined by fixed beams that work primarily in pitch mode. The forward pontoon consists of a single float which is acts primarily in heave mode. see www.seapower.ie for animation of fullscale device. The pontoons are designed to oscillate at resonant frequency relative to each other. This motion drives a syatem of a sea water pumps (C pumps) controlled by a Sea Power designed linear damping system.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 3/4
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 4m (1:36) model has been built with a power take off system which includes a scaled down C pump and stepped linear damping system. A fullscale design concept has been developed. Tank testing in Strathclyde in Mar 2010 indicated substantial power outputs. A full-scale numerical model has been developed and fully validated by tank testing in the Hydraulic and Maritime Research Center in Cork Ireland. The power output matrix shows a device capable of developing close to 4mw of power in the Belmullet test site off the coast of Ireland with an average annual power output in excess of 700kW.
Next development steps	The next devdelopment phase is to build a an approximately 1:9 scale device which will be aqpproximately 15 meters long. This device will be used to validate the substatial power matrix developed at the 4m scale, to test the sub systems, test the mooring design and carry out feasibility testing.
Power take off	
Dimensions	A totla length of 140m and a width of 29m - see animation of a fullscale device on our website www.seapower.ie

Centerline device spacing for multiple devices (m)	approximately 400m-500m
Weight of super structure (ton)	8500 Tonne Mostly concrete
Weight of power take off equipment (ton)	Estimate of 500 Tonne
Min installation depth (m)	25m
Max installation depth (m)	200m
Design lifetime (years)	25
Rated power (kW) of commercial unit	3.75MW
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Numerical Modelling (Simulation) validated by tank testing of a 4m device with a scaled Power Take Off and damping system.
Estimated date commercially available	2017
Estimated production cost per rated unit (EUR)	12m
Have environmental impact studies been performed	None
Discuss the survivability of the device and whether or not it has been tested.	Basic survivability testing of the 4m device has been carried out.
Technical publications	None
Figures/photographs of device have been attached to reply	Copy of animation of the fullscale device and video of the device being tested in the HMRC in Cork Ireland.
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	The device has a draft of approximately 4.5m so the minimum fjord depth is critical.1. Suspension Bridge - yes - all the device needs is mooring points. 2. Floating bridge - depends on whether mooring points are available. 3. Submerged Floating Tunnel - depends on the availability of mooring points.

Sea Power Platform

Power Matrix - Physical Modelling

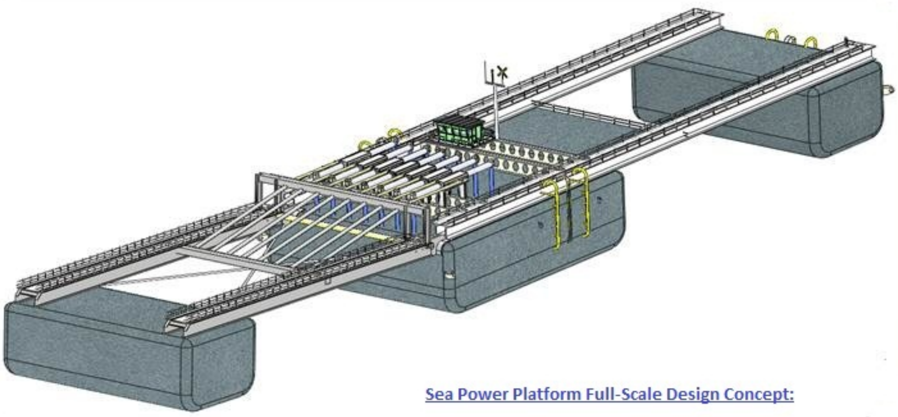
wave period - Tp (sec)

wave height - Hs (metres)	6	7	8	9	10	11	12	13	14
2	41	112	183	255	280	299	297	269	240
3	99	253	408	562	616	658	653	591	528
4	199	454	709	964	1059	1133	1123	1017	911
5	372	720	1067	1414	1569	1690	1674	1516	1359
6	625	1051	1477	1904	2136	2317	2294	2079	1863
7	971	1451	1931	2410	2740	2997	2964	2686	2409
8	1427	1921	2416	2911	3359	3708	3665	3322	2980

Power Matrix - Numerical Modelling

wave period - Tp (sec)

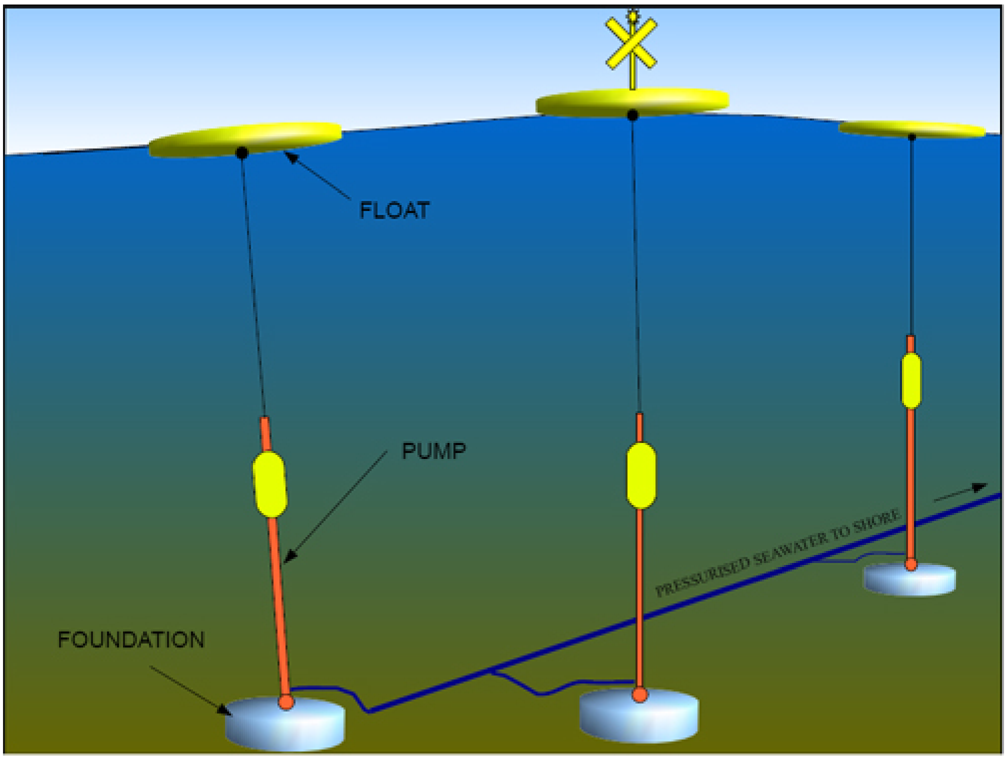
wave height - Hs (metres)	6	7	8	9	10	11	12	13	14
1									
2	34	65	144	248	318	322	312	297	268
3	74	140	311	537	690	703	683	652	590
4	129	239	531	917	1,183	1,210	1,178	1,129	1,026
5	201	365	808	1,395	1,798	1,843	1,798	1,726	1,572
6	289	515	1,133	1,952	2,517	2,585	2,527	2,431	2,220
7	392	686	1,500	2,581	3,327	3,426	3,355	3,234	2,962
8	509	876	1,905	3,271	4,217	4,353	4,272	4,126	3,791
9	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-



Sea Power Platform Full-Scale Design Concept:

Company	Seatricity Ltd
Country	UK
Web address	www.seatricity.net
Technology Name	Oceanus
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	Attenuator/point absorber
Features / Design principle	Arrays of buoy actuated reciprocating pumps produce hugh pressure seawater which is then transmitted ashore by pipeline and fed to a hydroelectric turbine.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A full size prototype has been tested at sea in Antigua for 2 years. A 1 megawatt demonstration is to be deployed at EMEC in May this year.
Next development steps	We are developing a project to deploy a 10 MW wave farm off the UK coast in 2013
Power take off	Hydraulic, seawater
Dimensions	Arrays of individual buoys, each 4.8 m dia.
Centerline device spacing for multiple devices (m)	30
Weight of super structure (ton)	1.2 ton
Weight of power take off equipment (ton)	0.5 ton
Min installation depth (m)	30 m
Max installation depth (m)	100 m
Design lifetime (years)	20
Rated power (kW) of commercial unit	30 kW per unit, 300 kW per sub array
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	Information can be provided under NDA
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Prototype monitoring
Estimated date commercially available	2012/13

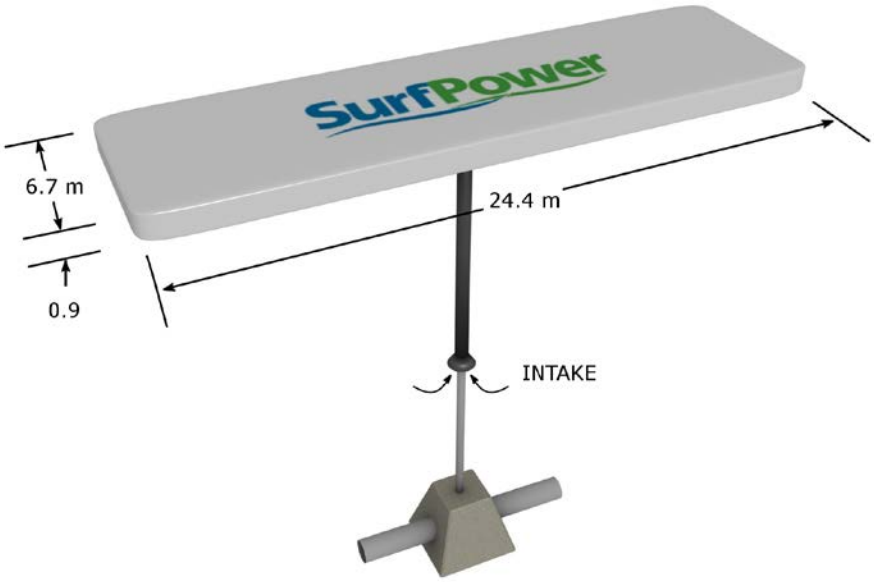
Estimated production cost per rated unit (EUR)	10c to 25c per kWh depending on wave climate, distance from shore, infrastructure requirements, cost of capital
Have environmental impact studies been performed	
Discuss the survivability of the device and whether or not it has been tested.	The devices have limited buoyancy and submerge in storm conditions
Technical publications	Documents can be provided subject to signing NDA. Patents have been granted for the technology.
Figures/photographs of device have been attached to reply	See website
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	It is likely that a bridge crossing a Fjord would be constructed inshore from the most energetic wave conditions, but it could be feasible in certain conditions.



Source - www.seatricity.net

Company	Seawood Designs Inc
Country	Canada
Web address	seawood@shaw.ca
Technology Name	SurfPower
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B) Point Absorber
Features / Design principle	Employs a rectangular buoyant wing that is anchored by a long stroke seawater pump. The system is designed to withstand rogue waves by submergence up to a depth of 10 m. Further, horizontal structural loading under storm conditions can be reduced to 25% of the normal operating conditions (this is an important consideration for bridge/tunnel mounting).
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 4/5
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:10 scale model was tested at the Canadian National Research Council's Institute for Ocean Technology located at Memeorial University, St. Johns, Newfoundland, Canada.
Next development steps	Seawood Drsigns Inc. is a member of a proposed program lead by the University of Victoria called "The West Coast Wave Initiative" that is tasked with refining current knowledge of the wave resource off the west coast of Vancouver Island and conducting studies as to how best to integrate wave energy devices. Seawood Designs plans to install a demonstration system in one of the areas under study on completion of the program.
Power take off	High pressure seawater driving a pelton turbine on shore. Operating pressure is constant at 70 bar. The turbine and alternator operate at constant speed thereby allowing for direct connection to the power grid.
Dimensions	Length 24.36 m, Width 6.7 m, Height 0.74 - 0.9 m.
Centerline device spacing for multiple devices (m)	32 m
Weight of super structure (ton)	21 metric tons
Weight of power take off equipment (ton)	not available
Min installation depth (m)	15 m
Max installation depth (m)	25 m

Design lifetime (years)	50 years
Rated power (kW) of commercial unit	300 kW
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	See Executive Summary Seawood Designs uses real time data to forecast energy recovery. We believe this is the most accurate approach as opposed to using modelled seastate conditions. In the event you wish to evaluate SurfPower further we would be pleased to use real time data for your sites to predict annual performance.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	See executive Summary
Estimated date commercially available	2015
Estimated production cost per rated unit (EUR)	Under development
Have environmental impact studies been performed	No
Discuss the survivability of the device and whether or not it has been tested.	The survivability of SurfPower has not been tested. Seawood Designs inc. believes Surfpower is highly unique in this regard. The system is designed to withstand total submergence to a depth of 10 m. It has the ability to cope with unexpected rogue waves by submergence. Further, the system has the ability to adopt a storm mode of operation that greatly reduces storm structural loading and power. This is the subject of patentable concepts and therefore can not be communicated at this time.
Technical publications	See Executive Summary Report Attached. Seawood Designs Inc. has contracted extensively with Dynamic Systems Analysis (Victoria, British Columbia) who have produced a number of reports that are confidential and the National Research Council of Canada has also produced a report that is confidential. These can all be made available should the need arise.
Figures/photographs of device have been attached to reply	See Executive Summary
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	SurfPower is ideally suited for mounting on a submerged floating tunnel. High pressure seawater is bumped down a hollow piston rod that would deliver the flow to the tunnel through a connection on the roof of the tunnel or at each side of the tunnel if the tunnel is wide enough to support a system on each side. The system could also be adapted for mounting on a floating bridge. The system cost would be reduced somewhat in that an allowance in pump stroke for tide would not be required. Also the pump could be anchored in a different way to make bridge mounting more cost effective.


SurfPower
6.7 m
24.4 m
0.9
INTAKE

Company	Shamil Ayntrazi
Country	USA
Web address	www.renewableenergypumps.com
Technology Name	Wind, Wave, Tidal and Deep Sea Water Air Conditioning
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	G
Features / Design principle	A Float following wave undulations transfers buoyant uplift to:Drive a pump to pump a small quantity of water to high head; collect and feed it to a hydro-turbo generator; Drive an electric “Isosync” VSG Generator precluding the need for rectifiers/chargers and invertors.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	No Prototype is made as testing must be in the sea at site, using a "Construction Unit"
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Simple Engineering Principles are used that can be easily verigied. All equipment are on the market and of best manugacture with proven performance.
Next development steps	Depends upon Client Site requirements
Power take off	Direct Drive
Dimensions	Construction Unit measure 22x22.5 m
Centerline device spacing for multiple devices (m)	CU at 25 m centerline
Weight of super structure (ton)	40 Tons
Weight of power take off equipment (ton)	5
Min installation depth (m)	15
Max installation depth (m)	100+
Design lifetime (years)	20
Rated power (kW) of commercial unit	Per Construction Unit: Wind 1.5 MW, Wave 350 KW, Tidal 90 KW, Solar 118.8 KW
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	Table Below
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Numerical simulations
Estimated date commercially	Immediate

available	
Estimated production cost per rated unit (EUR)	EU 1,500 per KW
Have environmental impact studies been performed	No Exceptional Impact
Discuss the survivability of the device and whether or not it has been tested.	The Construction Unit is anchored to the sea bed and can resist severe storms.
Technical publications	Search the Internet for Shamil Ayntrazi
Figures/photographs of device have been attached to reply	Yes in attached files
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	NO

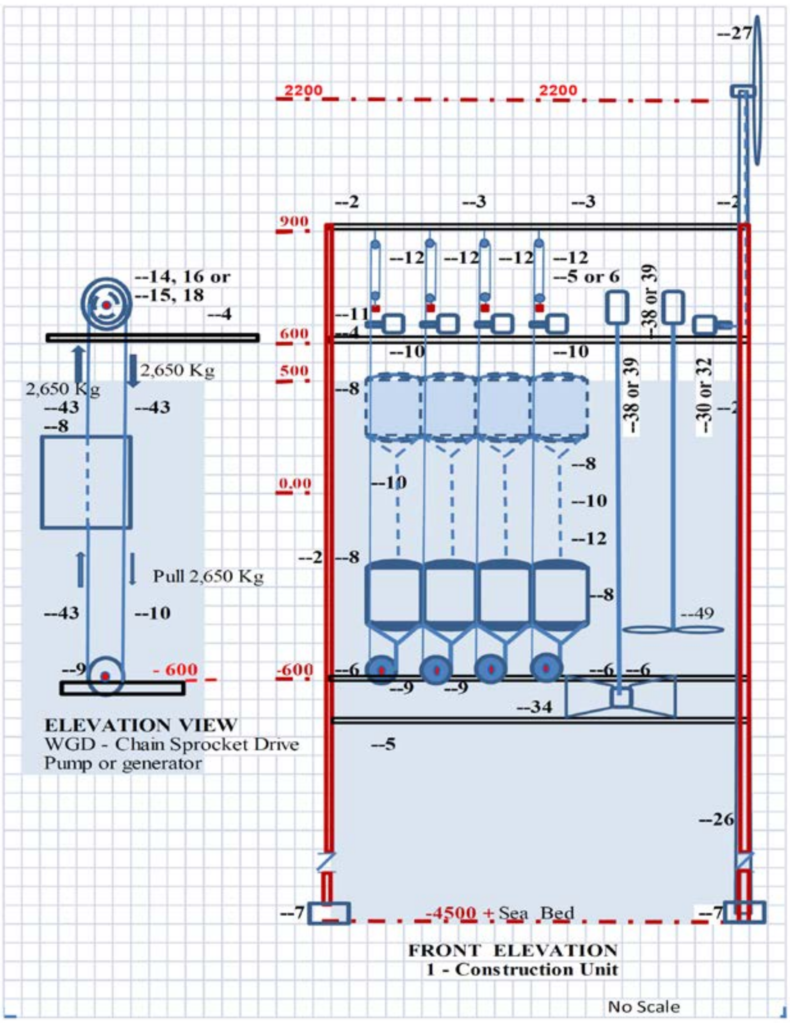
Table – 1 COEE ENERGY EXTRACTION per Kilometers

Present Wind Turbines	**Diam - m**	**Wind V -m/s**	**KW/Unit**	**No/C.U.**	C.U./Km	No/Km	Total MW/Km
Wind Turbine	126	14	20,691	N/App	N/App	4	82.77
Wind Turbine	Actual Output According to Nameplate						**20**
COEE System							
Wind Turbine	34	14	1,277	1	44	44	56.18
Wave Energy, Float 2m Diam, 1m Hi	Wave Hight m	No of P or G/Set	KW/Set of 4	Sets of 4P or G /C. Unit	C.Units per Km	Set/Km	
Wave Energy	4	4	35.02	10	44	44	15.41
Tidal Turbines	**TT Dia. m**	**Shroud D m**	**V/sec m**	**KW/TT**	**No./C.U**	**No/Km**	**Total MW/Km**
Tidal Turb. No Shroud	2	0	2	15	6	264	3.91
TT/Shroud - Recomend	2	6	2	133	6	264	35.23
TT With Shroud	??	20	2	1,483	1	44	65.24
Solar Energy	Area m2	E'gy KW/m2	Ex KW/m2	KW/C.U.	C.U./Km	No/Km	Total MW/Km
Solar Energy	495	1.368	0.240	118.8	44	44.0	5.2272
System	**MW/Km**	**KW-H/Km**					
Power 5 MW Wind Turbines	**82.77**	**40,000,000**	Name Plate 4x5 MW each WT (20MWx2,000H/Year)				
Wind Turbine	56.18	112,359,392					
Wave Power	15.41	42,793,256					
Tidal Turbine	35.23	257,194,800	**Highest due to availablity 20/24 hours per day**				
Solar MW	5.23	15,263,424					
Total COEE KW-Hour/Km	**112.05**	**427,610,872**					
As Compared to Wind Turbin	**82.77**	**40,000,000**					

Table – 2 COEE WAVE GEAR DRIVE PERFORMANCE

Total REWGD-P System Effi'cy						65%		Total REWGD-G System Efficiency						90%		
Wave Heit m	Water Pumped / 4 Pumps cm @ 65 m TDH			Energy Extr'd /4-Pump Kg-m		Energy Extr'd /4-Pump KW		Extraction Efficiency %		Pow er Gen c/o Pumps &HT KW		Pow er Gen c/o Generator KW		Wave Energy	Wave Duration	Energy Gen'd / Const'n Unit
	Total	Avge	Avge	Avge	Avge	Avge	Avge	Avge	Avge	1-Set of 4 Units		10 Sets per CU		2-m		
		162	360	162	360	162	360	162	360	Pumps	Gener	Pumps	Gener	KW	Hour/Y	KWH / Year
8.00	0.769	0.4855	0.22	31,555	14,200	308.75	138.94	53.60	24.12	90.31	125.04	903.10	1,250	576.00	2.60	3,251
7.00	0.631	0.3951	0.18	25,678	11,555	251.26	113.06	56.97	25.64	73.49	101.76	734.92	1,018	441.00	9.10	9,260
6.00	0.494	0.3056	0.14	19,862	8,938	194.34	87.46	59.98	26.99	56.85	78.71	568.46	787	324.00	27.40	21,566
5.00	0.358	0.2179	0.10	14,165	6,374	138.61	62.37	61.60	27.72	40.54	56.14	405.42	561	225.00	141.30	79,319
4.00	0.227	0.1359	0.06	8,836	3,976	86.46	38.91	60.04	27.02	25.29	35.02	252.90	350	144.00	610.40	213,740
3.00	0.125	0.0727	0.03	4,726	2,127	46.24	20.81	57.08	25.69	13.52	18.73	135.25	187	81.00	1,965.60	368,090
2.00	0.054	0.0284	0.01	1,847	831	18.07	8.13	50.20	22.59	5.29	7.32	52.86	73	36.00	3,494.20	255,728
1.00	0.012	0.0036	0.00	232	105	2.27	1.02	25.27	11.37	0.67	0.92	6.65	9	9.00	2,345.80	21,611
0.75	0.006	0.0013	0.00	85	38	0.83	0.37	16.43	7.39	0.24	0.34	2.43	3	5.06	2.60	9
Avg Pow er/Km "CU" 1-m w ave				0.41 MW		Total Generated per Year per Construction Unit - KWH										972,574
Avg Pow er/Km "CU" 4-m w ave				15.41 MW		Total Pumps or Generators/CU				40		Generation by 2,3,4 m waves				86%
Avg Pow er/Km "CU" 8-m w ave				55.02 MW		Foot Print per CU				22x22.5 m @ 2 m spacing						

FIGURE – 8 LAYOUT OF THE COEE DIRECT WAVE TURBINE DRIVE

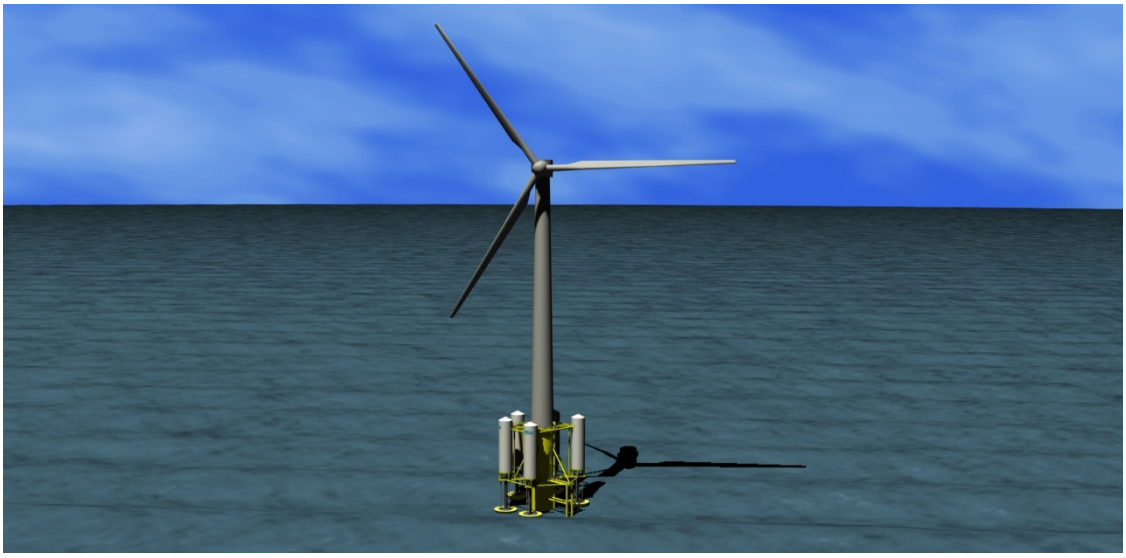


Page 11 of 11

Company	Trident Energy Limited
Country	UK
Web address	http://www.tridentenergy.co.uk
Technology Name	Wave Energy technology
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	A
Features / Design principle	Linear generator and integrated into a PowerPod product. Powerpods can be attached (co-located) onto a range of fixed marine structures (platforms)above the water. The PowerPod generator is driven by floats riding waves on the surface of the water. The linear generators convert the movement directly into electricity without additional gearboxes or hydralics.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL5/6
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Two 1:6 scale model tests in wave tank at Narec in Blyth UK. 8 full scale generators built and fully test on-shore. Tests have validated performance to system model. Planning sea trials in 2012 linked to off-shore wind turbine structure.
Next development steps	We are looking for partners to collaborate with us to complete sea trials.
Power take off	Low cost, patented, direct drive linear generator.
Dimensions	Tailored to suit wave climate. Hydrodynamic toolkit developed (wave to wire system model) to optimise product sizing and system to maximise efficiency, cost profile and IRR.
Centerline device spacing for multiple devices (m)	N/A
Weight of super structure (ton)	N/A as typically Co-located technology
Weight of power take off equipment (ton)	Configuarion dependent - more data available upon specific request.
Min installation depth (m)	N/A
Max installation depth (m)	N/A
Design lifetime (years)	25
Rated power (kW) of commercial unit	PowerPod is available in three sizes; 40, 80 and 150Kw per unit.

Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	Site and PowerPod configuration dependent - more detailed information available upon request/specific RFI From the report, the annual mean significant wave height ranges from 1.6 to 2.6m (Fig 3.1), annual wave power from 15 to 50kW/m (Fig 3.5) and annual mean wave energy period from 6.5 to 9s (Fig 3.7). This represents a large range of available wave power for which we would need to use different sizes of PowerPod depending on the specific site. Given that your intention is to install the wave energy converters in fjords which are presumably relatively sheltered we assume that the available wave power is most likely to be at the lower end of this range. We therefore estimate that our 80kW model would be most suitable. Trident Energy is developing the PowerPod technology through a rigorous R&D programme involving numerical modelling, prototype construction and testing in laboratory and operational conditions. Given our current level of understanding, we estimate that our 80kW PowerPod device would capture approximately 230MWh/yr in wave climates at the lowest end of the range, increasing with the available resource. Our 150kW PowerPod would be suited to sites in the medium to upper end of the stated range, capturing up to 770MWh/yr. We understand that you are exploring the potential for co-locating renewable energy generation on highway infrastructure. We would expect that many PowerPods could be deployed on such infrastructure at a packing density of around one every 10metres. Hence, the total energy yield per year needs to be multiplied up by the number of PowerPods deployed.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	tested in sinusoidal and polychromatic wave. Electromagnetic PTO enables dynamic device tuning to increase power conversion efficiency profile.
Estimated date commercially available	2014
Estimated production cost per rated unit (EUR)	€2mil per MW
Have environmental impact studies been performed	Yes
Discuss the survivability of the device and whether or not it has been tested.	Patented self protection system. Linear generaor is used to automatically lift floats out of the water. The self protection system has been tested

	successfully at full scale.
Technical publications	N/A
Figures/photographs of device have been attached to reply	Yes (attached to wind turbine are schematic drawings)
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Yes - keen to engage with technical knowledge transfer under NDA



Company	Vigor Wave Energy AB
Country	Sweden
Web address	www.vigorwaveenergy.com
Technology Name	Vigor Wave Energy Converter
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	G
Features / Design principle	The main component is a floating hose which follows the movements of the ocean waves. Letting in water and air into the hose creates batches that “surf” inside the hose. The batches’ movements create energy in the form of pressure. At the end of the hose, the water is pushed through a turbine, driving a generator that converts the pressure into electrical energy.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL4
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Small scale test were done in 2005. A CFD analysis follow up of these was done on a larger scale model. A 1/8 scale model is being developed in our wave tank facility at Vigor Wave Energy Wave Lab in Gothenburg.
Next development steps	We have started to look for a installation location to test a 1/4 size prototype. Testing is exptect to begin in 2013/2014
Power take off	Electrical turbine powerd by pressuriezd water and air.
Dimensions	The hose for the 1/4 size prototype is going to be 200 meter long, the conversion unit is about 8 cubic meters.
Centerline device spacing for multiple devices (m)	100
Weight of super structure (ton)	20
Weight of power take off equipment (ton)	5
Min installation depth (m)	20
Max installation depth (m)	200
Design lifetime (years)	20
Rated power (kW) of commercial unit	From 3 up to 100 MW

Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	The effeciency is so not interresting for us, we want to produce high amounts of energy at low costs. Contact us for more information.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	CFD analysis and numerical simulation/calculation
Estimated date commercially available	2016
Estimated production cost per rated unit (EUR)	200000 - 800000
Have environmental impact studies been performed	Initial brief studies have performed
Discuss the survivability of the device and whether or not it has been tested.	The device equiped with a remote operated survival system. When a storm is approaching, the device automatically will detect that it should go into survival mode and will be filled with water so that it submerges until the storm has passed. This system has not been tested.
Technical publications	Thorbergsson E. Modeling and simulation of the Vigor Wave Energy Converter,. University of Gothenburg, Göteborg 2009 Thorbergsson E. Vigor Wave Energy Converter, Energy Output Estimation,. Vigor Wave Energy AB, Göteborg 2010 Eskilsson C. CFD simulering av ett Vigor vågkraftverk med circular tvärsektion,. Chalmers teknikska högskola, Göteborg 2010 Alfredson H. Tryckfall i rörsegment Vigor Wave Energy,. Epsilon Utvecklingscentrum Väst AB, Göteborg 2010 Stensson C. Vigor Pressure drop calculations,. Epsilon Utvecklingscentrum Väst AB, Göteborg 2011
Figures/photographs of device have been attached to reply	Yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	It should be possible to combine this device to a fjord crossing.

Source - www.vigorwaveenergy.com

Company	Voith Hydro Wavegen
Country	Scotland
Web address	www.wavegen.com
Technology Name	
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	D
Features / Design principle	Nearshore fixed structure Oscillating Water Column with Wells Turbine power take-off
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 9
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	in 2000 Wavegen built the LIMPET facility on the Scottish Island of Islay. Full scale prototype devices have been tested and proven here delivering electricity to the National Grid for more than 70,000 turbine operating hours. In November 2011 the Mutriku wave energy plant was handed over to the Basque Energy Board (EVE) in Spain. THis plant contains 16 turbines and was the first commercially sold and operated wave energy plant in the world and the only multi-unit plant operating in the world.
Next development steps	Voith Hydro Wavegen are developing the Siadar project on the Scottish island of Lewis. This is an up to 30MW project of which 4MW is currently fully consented.
Power take off	Wells Tubrine (Bi-directional air flow, single direction of rotation) air turbine
Dimensions	Depends upon plant capacity which depends upon available wave resource at choisen location
Centerline device spacing for multiple devices (m)	As above
Weight of super structure (ton)	As above
Weight of power take off equipment (ton)	As above
Min installation depth (m)	≈7m
Max installation depth (m)	N/A
Design lifetime (years)	25 years
Rated power (kW) of commercial unit	18.5kW / 132kW

Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	I have specifically not completed the wave performance table. We are aware these tables are used by some developers to describe the performance of their device however it is not an approach we have utilised ourselves for a number of technical reasons (our Chief Technical Officer could explain more if required). We do however hope that our proven track record and our ability to demonstrate annual energy yield (which is of far more importance to a project) would provide far more information than could be obtained from completing this table.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Proven deployment
Estimated date commercially available	Now
Estimated production cost per rated unit (EUR)	N/A
Have environmental impact studies been performed	Yes, for all deployments
Discuss the survivability of the device and whether or not it has been tested.	Limpet has operated for over 11 years and has suffered no damage from severe weather.
Technical publications	Wavegen's Chief Technical Officer Dr Tom Heath has published many technical papers in the 20 years he has worked for Wavegen - too many to list
Figures/photographs of device have been attached to reply	Yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	This device is best integrated into a civil engineering structure

Company	Waveenergyfyn
Country	Danmark
Web address	http://www.Waveenergyfyn.dk
Technology Name	Crestwing
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G)atmospheric-suction pontoon absorber	G
Features / Design principle	The WEC has two pontoons which are fixed with hinges and the mechanical power take-off system is located above the hinge (PTO). During the up and down movement of the pontoons the potential atmospheric pressure will be utilized through the PTO system which generates electricity by a generator.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	1:30 scale proof-of-concept model was tested at AAU's wave laboratory in Ålborg Danmark 2008-9. 1:20 scale proof-of-concept including the proposed mooring system and PTO system model was tested at DHI's wave laboratory in Hørsholm Danmark 2010-11. 1:5 scale model including the proposed mooring and PTO system is tested off- shore in Frederikshavn, Danmark 2011-12
Next development steps	A full scale model is will be tested on the west coast of Jutland , Hanstholm Danmark 2012-15.
Power take off	Mechanical power take off
Dimensions	Each of the two full scale sections is 13,5 m wide and has a length of 40 m, for a total
Centerline device spacing for multiple devices (m)	20 -40
Weight of super structure (ton)	70
Weight of power take off equipment (ton)	6
Min installation depth (m)	10
Max installation depth (m)	150
Design lifetime (years)	20 - 30
Rated power (kW) of commercial unit	200

Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	40% - 45%
Source of wave energy absorption performance (numerical simulations or random wave model tests)	irregular 3D waves
Estimated date commercially available	2017-01
Estimated production cost per rated unit (EUR)	5.00E+05
Have environmental impact studies been performed	no
Discuss the survivability of the device and whether or not it has been tested.	The mooring system has gone through long-term test on DHI wave laboratory in Hørsholm Denmark 2010-11 and anchoring forces are tested under all possible conditions. The forces in the anchor chain of a North Sea installations will from Hs = 2m not be increasing with wave height.
Technical publications	There are published seven reports of Test procedures
Figures/photographs of device have been attached to reply	
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	Very possible but energy content must remain at a reasonable level

Source - http://www.Waveenergyfyn.dk

Company	Wavestar A/S
Country	Denmark
Web address	www.wavestarenergy.com
Technology Name	wave star
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B
Features / Design principle	20 buoys fixed on rotated arms, based on a structure upside to the water line. The up and down movement of the buoys is transformed in high hydraulic pressure and turns a generator
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8-9
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	1:40 scale tested at AAU in 2004 1:10 (ø1m flyder) scale installed at Nissum Bredning in 2006 2xø5 m flyder scale installed at Hanstholm in 2009 (part of the full scale model) 20xø6m flyder scale full C6 section to be installed at Horn Reef 2 in 2014
Next development steps	development and construction of the full version to HR2
Power take off	hydraulic
Dimensions	80x17x5
Centerline device spacing for multiple devices (m)	
Weight of super structure (ton)	1600
Weight of power take off equipment (ton)	40
Min installation depth (m)	10
Max installation depth (m)	30
Design lifetime (years)	20
Rated power (kW) of commercial unit	600 kW
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	40-50%
Source of wave energy absorption performance (numerical simulations or random wave model tests)	numerical simulation and reallife test results from protype in Hanstholm
Estimated date commercially available	2014
Estimated production cost per rated	7 mio €

unit (EUR)	
Have environmental impact studies been performed	no
Discuss the survivability of the device and whether or not it has been tested.	automatic detcetion of storm by wave measurement, data from StormGeo, the system lift automatically the buoys and arm and the all platform to the storm protection level (patented system)
Technical publications	Rico Hansen/Morten Kramer, Modelling and control of the Wavestar prototype, EWTEC 2011. Morten Kramer, Peter Frigaard, Laurent Marquis,Performance evaluation of the Wavestar prototype, EWTEC 2011. Laurent Marquis, Morten Kramer, Peter Frigaard,First production figures from the Wavestar Roshage Wave energy converter, ICOE 2010.
Figures/photographs of device have been attached to reply	yes
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	the device can be used as a breakwater on coast line, or in a cobination with wind turbine inside wind farm

Source - www.wavestarenergy.com

Reply Wavestar C6 machine

Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p)

Harvested power [kW]

Hm0 range [m]	Hm0 [m]	Wave period T0,2 [s]															
		0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	14 - 15	15 - 16
		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5
0.0 - 0.5	0.25	0.0	0.7	4.9	14.8	28.8	43.6	54.0	55.3	55.2	55.3	52.8	50.6	48.3	45.5	44.3	42.3
0.5 - 1.0	0.75	0.0	5.9	43.7	133.2	241.1	275.2	273.7	254.6	236.1	218.5	202.9	189.3	178.8	168.1	160.0	152.0
1.0 - 1.5	1.25	0.0	16.3	121.3	368.1	554.5	574.2	530.7	485.3	439.1	401.6	369.8	344.0	322.9	303.6	287.1	271.6
1.5 - 2.0	1.75	0.0	32.0	237.7	698.9	931.1	906.8	819.2	731.9	659.4	598.3	550.0	509.8	476.5	446.5	421.6	397.9
2.0 - 2.5	2.25	0.0	52.8	393.0	1097.8	1344.0	1262.5	1125.8	998.8	893.4	809.5	740.3	683.5	637.2	595.8	561.1	530.3
2.5 - 3.0	2.75	0.0	78.9	587.0	1557.6	1787.1	1640.7	1452.3	1280.4	1140.3	1028.4	937.9	865.2	805.4	752.4	707.3	666.0
3.0 - 3.5	3.25	0.0	110.2	819.9	2054.9	2262.2	2041.1	1796.4	1574.4	1398.7	1258.3	1145.1	1048.9	978.0	912.8	857.7	807.1
3.5 - 4.0	3.75	0.0	146.7	1091.6	2593.0	2759.4	2464.2	2152.4	1886.3	1667.0	1490.0	1355.7	1244.6	1156.0	1077.6	1011.1	950.2
4.0 - 4.5	4.25	0.1	188.5	1401.9	3157.0	3282.9	2901.1	2521.1	2203.4	1940.9	1732.7	1573.4	1442.3	1337.2	1245.1	1166.9	1095.9
4.5 - 5.0	4.75	0.1	235.4	1751.6	3761.2	3815.1	3353.5	2908.7	2528.4	2223.9	1985.0	1795.6	1642.8	1521.4	1414.8	1325.0	1243.9

remark: harvested energy of ø6mx20 (all C6 machine) floats including float interaction

Company	Waveberg Development
Country	USA
Web address	www.waveberg.com
Technology Name	Waveberg
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	A
Features / Design principle	Waveberg is an asymmetrical series of hinged floats driving pumps, which pressurize seawater for delivery to shore via flexible pipes. The overall triangular shape in plan view assures each portion of the device receives fresh wave crest.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 5/6
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	1:15 scale model in tank tests, NRC Canada Newfoundland. Same model in sea trials for 14 months, scaled equivalent 6 years. 1:4 model tested in Florida waters, survived storm. Model was sabotaged. 1:32 model tested at HMRC in 2006, 2007 and 2009 in several configurations. The data from the latest is used for the rest of this presentation.
Next development steps	Seeking investment. Until EUR 2,300,000 is raised, no further steps. Following investment, two years to completion of full-scale test at EMEC.
Power take off	Hydraulic using sea water
Dimensions	Triangle 53 m base by 53 m lengtht.
Centerline device spacing for multiple devices (m)	100m
Weight of super structure (ton)	15
Weight of power take off equipment (ton)	1
Min installation depth (m)	15
Max installation depth (m)	none
Design lifetime (years)	12
Rated power (kW) of commercial unit	125
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of	varies, typical 30% of wave energy absorbed across frequencies.

significant wave height and peak wave period ****	
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Regular wave tests converted to outputs in real seas.
Estimated date commercially available	3 yr after funded
Estimated production cost per rated unit (EUR)	EUR 280000
Have environmental impact studies been performed	none
Discuss the survivability of the device and whether or not it has been tested.	Storm survival is assured by low weight and draft not engaging the wave and by releasing the PTO from shore, so floats can move freely.
Technical publications	none
Figures/photographs of device have been attached to reply	See website.
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	No

Source - www.waveberg.com

Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p)

H_s (m) \ T_p (s)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
10										125	125	125	125	113	113	88	88	88
9.5									125	125	125	125	125	110	110	86	86	86
9									125	125	125	125	125	107	107	84	84	84
8.5								125	125	125	125	125	125	102	102	80	80	80
8							125	125	125	125	125	125	125	96	96	75	75	75
7.5							125	125	125	125	125	125	119	90	90	70	70	70
7						125	125	125	125	125	125	125	110	83	83	65	65	65
6.5					125	125	125	125	125	125	125	125	100	75	75	59	59	59
6				125	125	125	125	125	125	125	125	125	90	68	68	53	53	53
5.5			125	125	125	125	125	125	125	125	125	111	79	60	60	47	47	47
5			125	125	125	125	125	125	125	112	121	87	62	47	47	37	37	37
4.5			125	125	125	125	125	125	116	102	111	79	57	43	43	34	34	34
4			125	125	125	125	125	105	99	90	97	70	50	38	38	29	29	29
3.5			125	125	125	125	125	114	113	110	119	85	61	46	46	36	36	36
3			118	125	125	125	106	101	111	121	125	94	67	51	51	40	40	40
2.5			117	125	125	125	94	82	90	84	91	65	47	35	35	28	28	28
2			86	121	115	96	81	67	57	54	58	42	30	23	23	18	18	18
1.5			67	125	88	67	47	36	30	25	27	20	14	11	11	8	8	8
1			38	85	48	34	22	15	12	9	10	7	5	4	4	3	3	3
0.5			9	20	13	9	5	3	3	2	2	2	1	1	1	1	1	1
0.125			1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

Note: values for long wave, > 25 sec. are crudely interpolated here. No values for waves <5 secs done in tank tests.

Company	WavePiston ApS
Country	Denmark
Web address	http://www.wavepiston.dk
Technology Name	WavePiston
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	Multiple attenuators mounted on the same string. G with strong elements of A
Features / Design principle	Wavepiston is a long (several wavelengths) load-bearing structure whereupon a large number of vertical plates are mounted. The vertical plates are forced into horizontal movement by of the oscillating wave movement. The most important feature of the WavePiston system is the employment of force cancellation. As the elongated structure have a length of several wavelengths, each plate in the structure will be subjected to a different load due to the stochastic nature of wave movement. Depending on the phase of the waves acting on the individual plates the force will either be in the direction of the waves or against the direction of the waves. Thus, the sum of the forces acting on all plates will be relatively small, as the force on counter-moving plates will tend to cancel each other out. To satisfy the need for robustness every sub-system in the WavePiston concept has been constructed with simplicity and robustness in mind. A prime example on this design philosophy is the power-takeoff system. Although a system employing linear generators might prove more efficient, the power-takeoff system of WavePiston is based on simple, reliable and rugged hydraulics operated at low pressure. This solution is cheap, robust and completely impervious to ingress of seawater, hence promising a long lifetime without maintenance. An important additional benefit of having a very long device is that large waves will only hit a small part of the structure at a time. Therefore this device has an intrinsic ability to handle freak waves.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 5/6

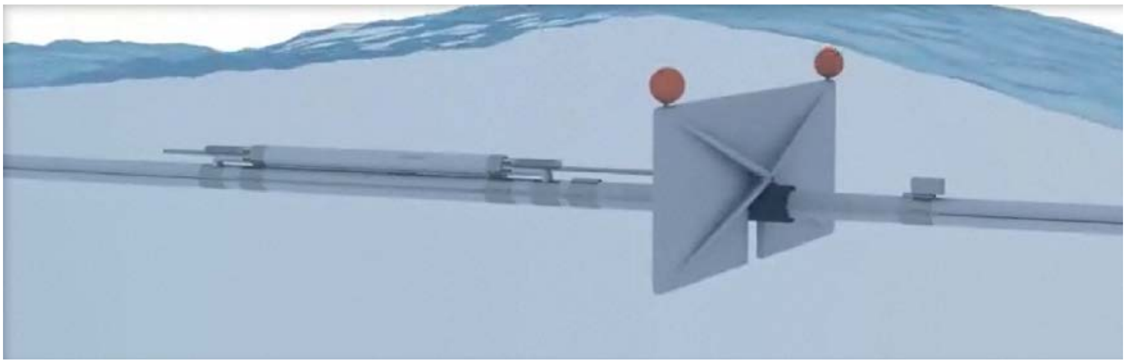
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:30 prototype has been extensively tested at the University of Aalborg, the leading Danish authority within the field of wavepower. The scale was given by the depth of the test bassin, since a simulated water depth of 30 meters was the goal of the test. The testing was highly successful and resulted in a subsequent M.Sc. project.
Next development steps	Currently negotiations are carried out between WavePiston ApS and GEDI, the leading Chinese authority on design of power systems. GEDI will probably deploy a 1:1 prototype of the WavePiston system off the Chinese coast in 2012 or early 2013. WavePiston is also negotiating with a (anonymous) Chinese producer of GFRP to start a joint development of a complete energy producing system using WavePiston technology. If this collaboration is fruitful it will be possible to buy a plug'n play system directly from the producer.
Power take off	Hydraulic, using sea-water as working fluid. Seawater is environmentally neutral. If sea-water is pumped to a reservoir instead of direct power production, this will allow for efficient storage until the power is needed.
Dimensions	A very important advantage of the WavePiston principle is the complete flexibility to tailor the system to any sea condition. The only dimension which is fixed is the length of the main string which should be at least one wavelength and preferably >2 wavelengths in order to take full advantage of the patented force cancellation principle. A fair guess on a system suitable for your purpose is strings having a length of 300 m fitted with 15 pumps each. As for the width of the system, there is no real limit. The system can be a narrow as one string and as wide as the entire cost-line if enough strings are placed side by side. Note that the system operates almost fully submerged and will be virtually invisible from the coast. If the limited visibility is a problem the buoys placed in the end of the strings can be configured with a high visible cross-section.
Centerline device spacing for multiple devices (m)	The spacing between individual strings is dependent on the wanted efficiency of the system. For a high efficiency system (40-50%) the strings will be placed with a distance of 20m. A low efficient, low impact system having an efficiency of about 20% will have a string spacing of 50m. Note that the high efficiency system will comprise guidelines and side anchors to prevent clashing of the strings in erratic wave conditions.

Weight of super structure (ton)	No superstructure, system operating fully submerged. Generator is placed onshore.
Weight of power take off equipment (ton)	Depends again on the rated power of the system. For a 1MW system the estimated weight of turbine + generator is 2 metric tonnes.
Min installation depth (m)	Outside surf-zone.
Max installation depth (m)	No limitations, however anchoring in very deep waters might render the concept to costly.
Design lifetime (years)	Depends on design. 15 or 20 years is realistic for fully developed system. WavePiston relies on standard mooring techniques developed for off-shore applications. The pumps will need service during the 20 years lifespan.
Rated power (kW) of commercial unit	The unit currently developed in collaboration with WavePiston and an (anonymous) Chinese producer is intended for off-grid applications and have a rating of 30 kW. The design philosophy of WavePiston is that systems should be specifically designed to the waters where it is depolyed, taking into account the locale wave climate. Due to the modularity of the WavePiston system this customized design is extremely simple and will always result in the most cost efficient solution. WavePiston systems comprises a multitude of strings all coupled to the same turbine/generator. For a grid-connected energy harvesting park a sensible unit size will be 1MW. (Unit = turbine/generator + 10 strings)
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	No definite numbers can be given here as the performance depends (among other things) on the dimensions of the plates, the density of pumps, the operating pressure of the system and the length of the strings which are all freely selectable. As a rule of thumb the design study of the WavePiston system made for the North Sea has an average efficiency of 30%, where the efficiency @ lower wavestates is > 60% and the efficiency at high wavestates is < 20%. The wavestate dependent efficiency is a very desireable feature since this allows some water movement in the waters behind the system since minimizing the environmental impact of the wave power system. Also, a 100% efficiency at high wavestates would mean that the PTO system would be very expensive as it should be able to handle very high energies for comparably small periods of time.

Source of wave energy absorption performance (numerical simulations or random wave model tests)	2D wave experiments was carried out by WavePiston ApS as well as by staff at the University of Aalborg. The measurements has formed the basis for a thesis on WavePiston. The thesis can be sent to you upon request. Subsequently to the experiments WavePiston has refined the (1D)numerical methods originally devised by Niras (Report can be found in the document section of the WavePiston wavesite) The (1D)numerical method will form the basis for any initial design, however there is currently no substitute to wave-tank experiments if detailed performance in real 2D waves is wanted. The claimed efficiencies is based on experimental measurements.
Estimated date commercially available	Autumn 2013, however blueprints exist and work on first prototypes could start within 2 months from decision.
Estimated production cost per rated unit (EUR)	1 EUR / installed watt, excluding grid connction. Thus, a 1 MW system would cost 1 MEUR
Have environmental impact studies been performed	No, but there is really no reason that the system would have any environmental impact since this is a floating structure shunting some (but not all) of the wave energy. The amount of shunted wave-energy is a design parameter and can be chosen freely.

Discuss the survivability of the device and whether or not it has been tested.	The WavePiston concept was specifically designed with survivability in mind, using the inventors profound knowledge on offshore requirements. The WavePiston system is very long. Hence a freak wave hitting the system will only affect a small part of the system at the same time. Consequently, the WavePiston system is immune to freak-waves which is the biggest threat to this type of systems. The systems comprises pressure compensators which double as swim bladders. Upon filling the swim bladders with water the system can avoid storms by submerging. The submerging system also allows ships to sail over the system. Every exposed component of the WavePiston system is kept simple and waterproof. The survivability has NOT been tested in real sea conditions. The very concept has been designed with survivability in mind, by off-shore engineers for an off-shore environment. First of all the elongated structure of the strings spanning over several wavelengths make the system intrinsically resistant to freak waves (rouge waves). In fact, any structure other than elongated structures will always be very vulnerable to these waves. Is a storm rises the system is designed to submerge and hence run away from large waves. Due to the modularity of the system a pump may fail without compromising the function of a string. A string may fail without compromising the function of the whole system (a system comprises one turbine/generator unit and several strings)
Technical publications	Experimental Study on the WavePiston Wave Energy Converter. / Pecher, Arthur ; Kofoed, Jens Peter ; Angelelli, E..Aalborg : Aalborg University. Department of Civil Engineering, 2010. 28 p. (DCE Contract Reports; 73). Experiments on the WavePiston, Wave Energy Converter Angelelli, E., Zanuttigh, B. et al. 9th ewtec 2011 University of Southampton 2011 Title: Robustness and Force Cancellation - the Keys to Commercial Wave Power Generation Dr.Kristian Glejbol, Founding Parterners, WavePiston ApS, Denmark LCES, Dalian 2011
Figures/photographs of device have been attached to reply	Please see our homepage www.wavepiston.dk

Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	This device is superbly fitted to attach to a suspension bridge or a floating bridge, where the bridge can act as superstructure for the generator/turbine system. This device could be fitted to a submerged floating tunnel hereby reducing the mooring costs.



Source - http://www.wavepiston.dk

Company	W4P Waves4Power AB
Country	Sweden
Web address	www.waves4power.com
Technology Name	WaveEL-buoy
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	B
Features / Design principle	The WaveEL works by principle of a two body oscillating system. The buoy with the characteristic long vertical acceleration tube below and the water column in the tube. The movement of a the water column is dampened by a water piston which is connected to a hydraulic piston in a cylinder. By loading the hydraulic piston the relative motion between the wave induced heave of the buoy/tube and the large water mass – that is still and not affected by the wave motion – is dampened and a gigantic hydraulic pump is created which pumps oil to a hydraulic motor which in turn rotates a generator.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	Smaller scale IPS-buoys were tested in the mid 1970-1980 by sister company IPS InterProject Service. First fullscale test by IPS in 1980-81 west of Vinga. Waves4Power have tested a new full scale version of an improved IPS-buoy - now called WaveEL-buoy - in the summer of 2010. W4P is now preparing tests of a third generation full scale buoy and the building of a small grid connected pilot plant on the Swedish west coast.
Next development steps	A pilot plant off the coast of Bohuslän with 4 grid connected buoys and the testing of a larger buoy off the coast of Norway or Portugal in the next two years.
Power take off	Oil hydraulic
Dimensions	Buoy diameter 4-10 meters. Acc. Tube 20 - 35 meters deep.
Centerline device spacing for multiple devices (m)	35
Weight of super structure (ton)	45
Weight of power take off equipment (ton)	5

Min installation depth (m)	50
Max installation depth (m)	150
Design lifetime (years)	25
Rated power (kW) of commercial unit	250kW
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	As the device dimensions will be optimized for the prevailing wave state, there is no relevant way to fill the Wave Performance sheet without having access to a scatter diagram for the particular site for which the device is to be used.
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Numerical simulations
Estimated date commercially available	2018
Estimated production cost per rated unit (EUR)	200kEUR
Have environmental impact studies been performed	No
Discuss the survivability of the device and whether or not it has been tested.	The device has been ocean tested but not in at hurricane level. The device is by its axisymmetric shape and small dimensions in relation to the wave length in which it operates gives it an inherent great survivability. Mooring systems have been tested in wave tank, computer simulated and ocean tested but not in hurricane winds. The system is considered safe. The buoy has a patented overload feature that prevents the energy conversion system from pushing beyond its limits even in extreme waves.
Technical publications	There are more than a dozen independent white papers written on the IPS-buoy principle when used with different power take off systems, most well-known are the works of Prof. Antonio Falcao at Institute Superior Technology in Lissabon and also work by B-O Sjöström at the department of Civil Engineering (Väg och Vatten Byggnad) at CTH.
Figures/photographs of device have been attached to reply	
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	The WaveEL-buoy is free floating and can be moored to a floating or fixed structure as long as the water depth is sufficient for the acceleration tube.


Source - www.waves4power.com

Company	Wello Ltd.
Country	Finland
Web address	http://www.wello.eu/
Technology Name	Penguin
Device Type ** A) Attenuator B) Point Absorber C) Oscillating Wave Surge Converter D) Oscillating Water Column E) Overtopping/Terminator Device F) Submerged Pressure Differential G) Other Designs	G
Features / Design principle	The Penguin is fully sealed floating generator platform with all moving parts inside the platform. Wave energy is converted directly to electricity inside the floating equipment and connected to national electricity network.
Development status *** TRL 1-3, TRL 4, TRL 5/6, TRL 7/8 or TRL 9	TRL 7/8
Description of any and all prototypes (including test facility used or location of testing, dates, and hours of operation)	A 1:18 scale tested both in wave tank and at sea,Helsinki University of Technology 2008-11. A 1:8 scale model storm survivability tested in sea condition at Baltic Sea 2011. Full scale tests starting spring 2012 in Orkney, Scotland.
Next development steps	Full scale device installation ongoing in Orkney, Scotland.
Power take off	Direct from motion to generator
Dimensions	length 30m, width 15m, draught 7m and above water 1,8m.
Centerline device spacing for multiple devices (m)	100
Weight of super structure (ton)	1400
Weight of power take off equipment (ton)	65, included to superstructure
Min installation depth (m)	50
Max installation depth (m)	150 (- - 1500, adjusted mooring)
Design lifetime (years)	25
Rated power (kW) of commercial unit	1000
Wave energy absorption performance (kW) (before losses in conversion to electric power) as a function of significant wave height and peak wave period ****	See below
Source of wave energy absorption performance (numerical simulations or random wave model tests)	Random wave model tests and numerical simulations
Estimated date commercially	2012-10

available	
Estimated production cost per rated unit (EUR)	5,000,000
Have environmental impact studies been performed	Yes
Discuss the survivability of the device and whether or not it has been tested.	Mooring arrangement is verified by DNV. 1:8 scale model has survived 100-years storm
Technical publications	Multiple patent applications
Figures/photographs of device have been attached to reply	Yes, see also: http://www.youtube.com/watch?v=FlCXnCUis8g, http://www.youtube.com/watch?v=iljClsPvigs
Is it possible to combine this device with a fjord crossing that implements a suspension bridge, floating bridge, or submerged floating tunnel. If so, how?	This device is best suited for offshore applications. Combining might be usefull for cable routing to ease grid connection.

Wave energy conversion absorption performance (kW) as a function of significant wave height (H_s) and peak wave period (T_p). **Only tested values shown.**

H_s (m) \ T_p (s)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10																		
9.5																		
9																		
8.5																		
8											Not tested							
7.5																		
7																		
6.5											846	778						
6										929	780	717						
5.5									961	855	716	658						
5								941	870	773	648	596						
4.5							808	850	785	697	584	536	Not tested - most likely similar values as T7-T11, design can be further optimized to specific wave spectrum					
4						652	716	755	698	620	520	478						
3.5						575	629	662	611	542	454	417						
3					373	491	532	562	520	462	387	356						
2.5					311	408	441	470	440	394	329	301						
2					243	326	358	377	349	310	260	239						
1.5						197	206	225	214	194	161							
1																		
0.5																		
0.125																		

Appendix 7: Fjord crossing locations

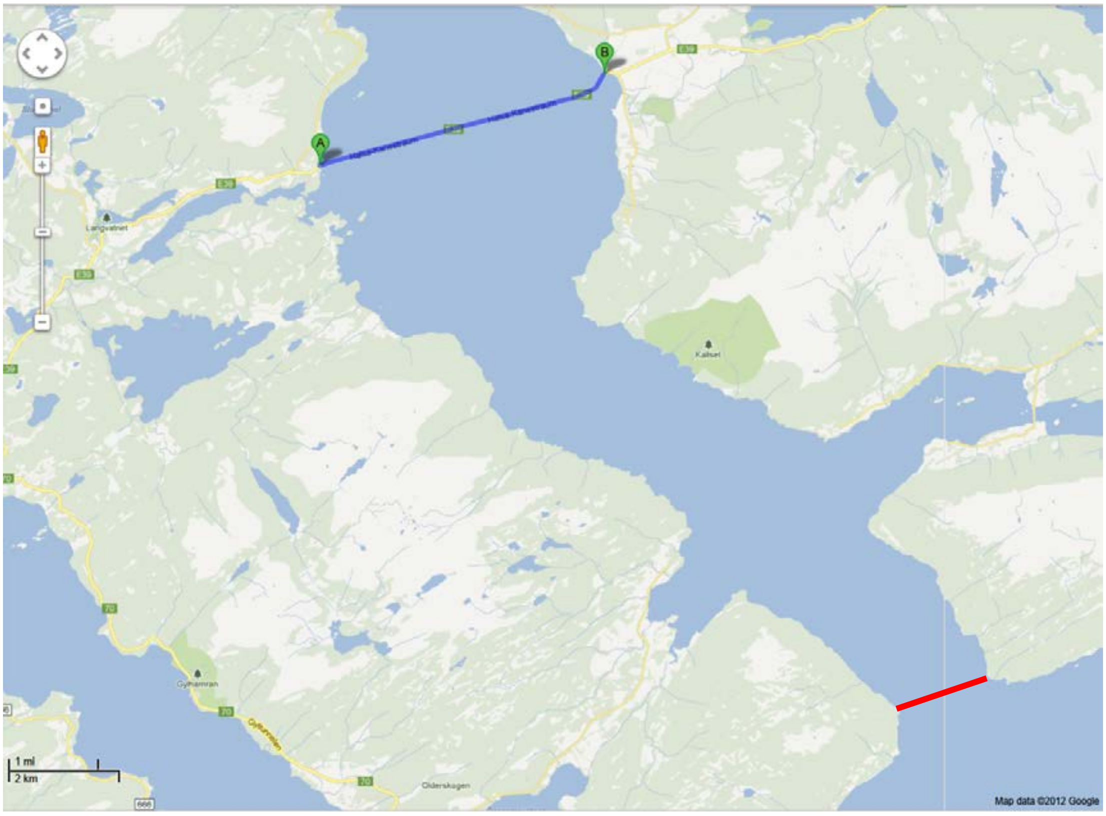


Figure A7:1 Proposed crossing for Halsafjord [24].

Figure A7:2 Proposed crossing for Moldefjord [24].

Figure A7:3 *Proposed crossing for Storfjord [24].*

Figure A7:4 *Proposed crossing for Voldafjord [24].*

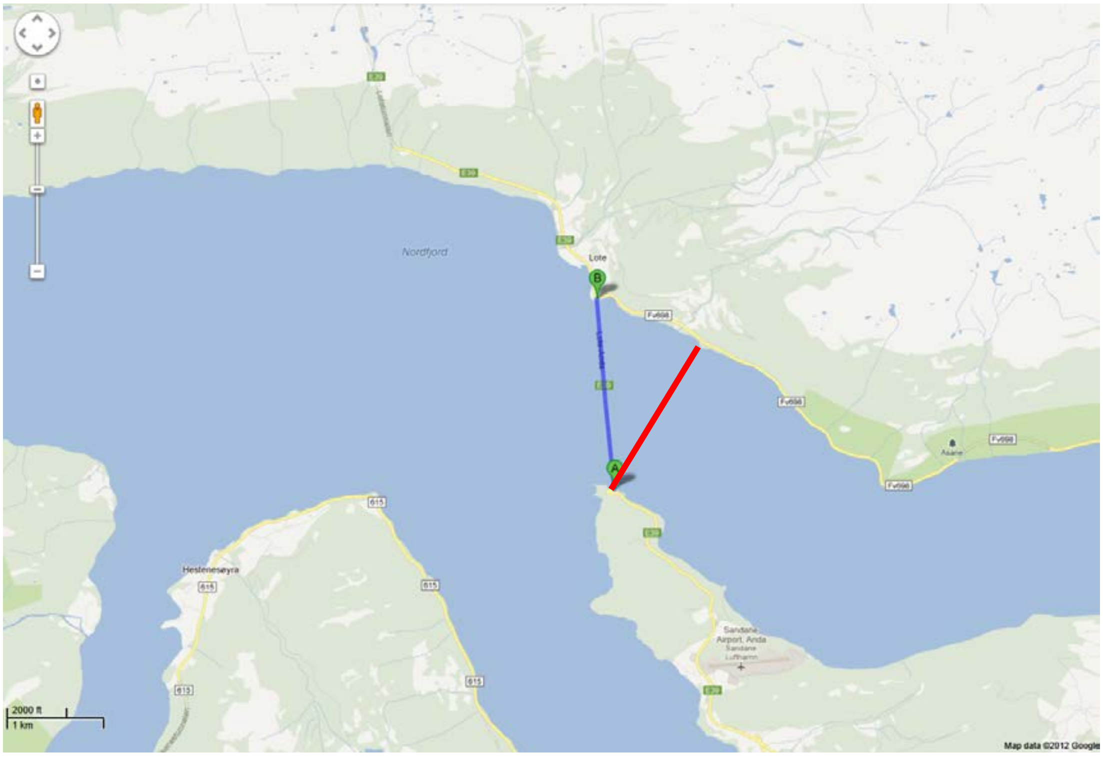


Figure A7:5 Proposed crossing for Nordfjord [24].

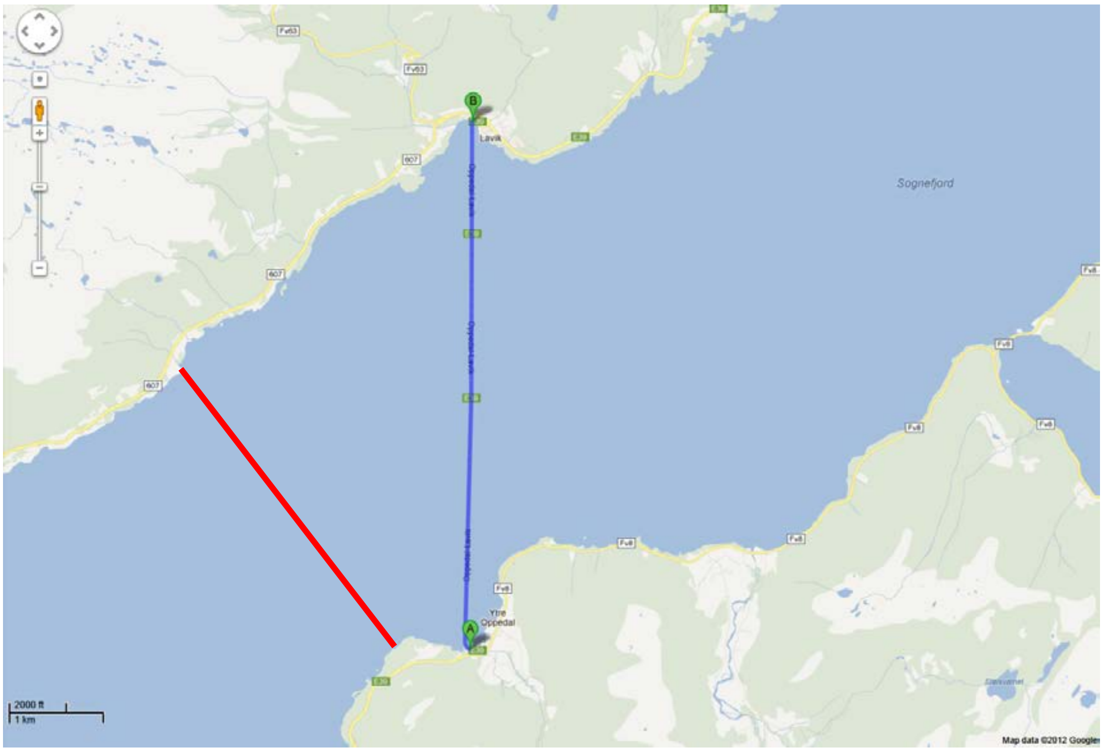


Figure A7:6 Proposed crossing for Sognefjord [24].

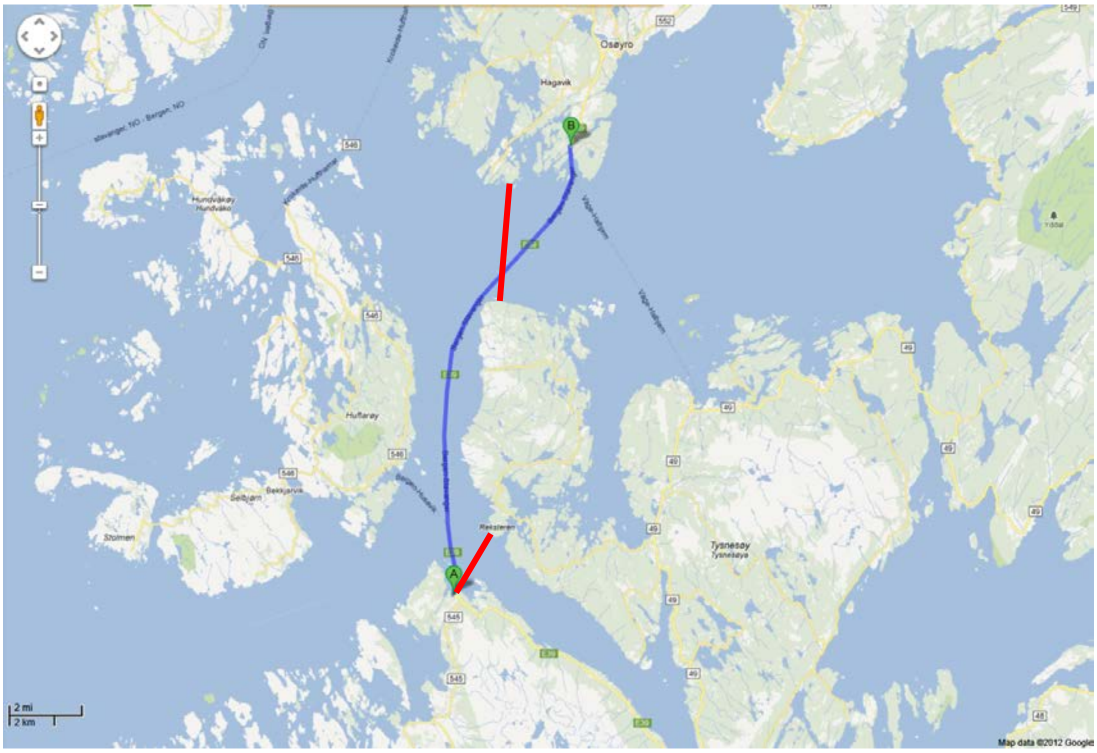


Figure A7:7 Proposed crossings for Bjørnafjord a and Bjørnafjord b [24].

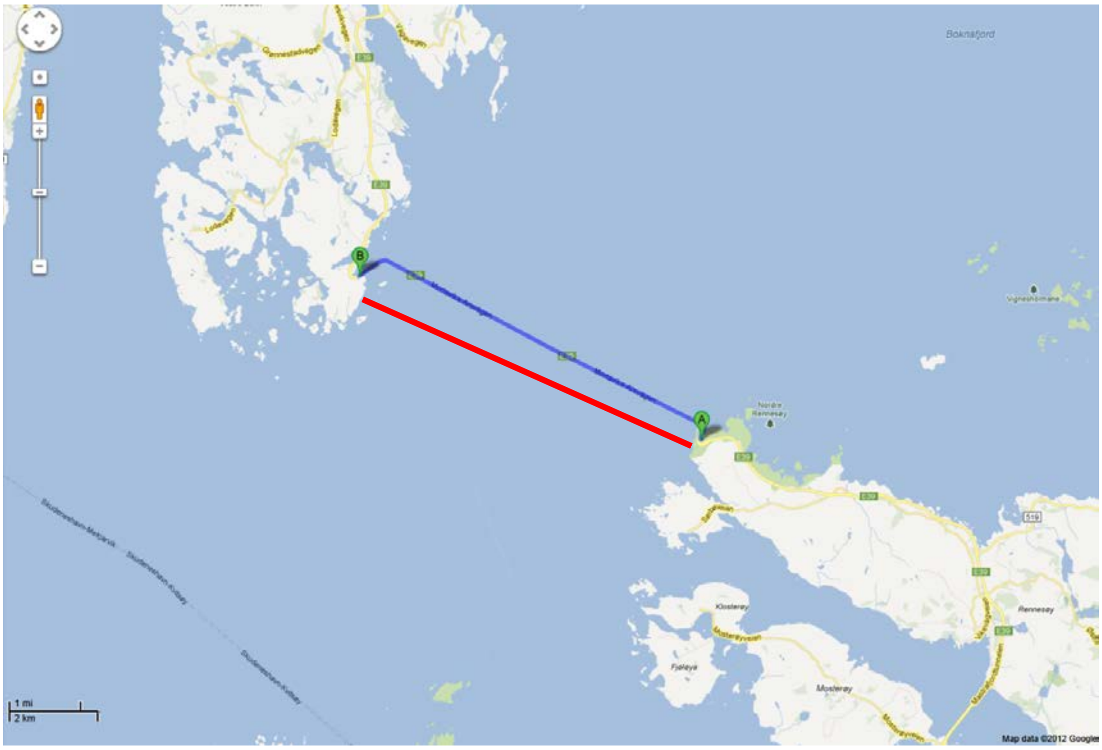


Figure A7:8 Proposed crossing for Boknafjord [24].

Appendix 8: Calculations of the number of TISEC devices

Table A8:1 Number of TISEC devices for the different fjord crossing locations.

Technology	W_{dev} (m)	L_{dev} (m)	Moldefjorden (Crossing # 2) $N_{tot\_sus/float}$	Moldefjorden (Crossing # 2) N_{tot_SFT}	Voldafjord (Crossing # 4) $N_{tot\_sus/float}$	Voldafjord (Crossing # 4) N_{tot_SFT}	Nordfjord (Crossing # 5) $N_{tot\_sus/float}$	Nordfjord (Crossing # 5) N_{tot_SFT}	Boknafjord (Crossing # 8) $N_{tot\_sus/float}$	Boknafjord (Crossing # 8) N_{tot_SFT}
Atlantis Resources Corp	18	18	282	239	59	50	47	40	296	251
BioPower Systems Pty Ltd	17	17	298	253	62	53	50	42	313	266
Hales Energy Ltd	-	-	-	-	-	-	-	-	-	-
Hammerfest Strom Small	20	20	253	215	53	45	42	36	266	226
Hammerfest Strom Large	21	21	241	205	50	42	40	34	253	215
HPS AS	6	32	434	370	90	78	72	62	456	388
Hydro-Gen *)	3.57	3.57	2850	2422	600	510	484	410	2992	2544
Kepler Energy	10	120	60	51	12	10	10	8	64	54
Nautricity Ltd	14	14	362	308	76	64	61	52	381	323
Neptune Renewable Energy Ltd	11	11	462	392	97	82	78	66	485	412
Norwegian Ocean Power Small *)	12.65	12.65	401	341	84	71	67	57	421	358
Norwegian Ocean Power Large *)	22.36	22.36	226	192	47	40	38	32	238	202
Ocean Flow Energy Limited Small *)	5.08	5.08	2000	1700	420	358	338	288	2100	1784
Ocean Flow Energy Limited Large *)	16.0	16.0	317	269	66	56	53	45	333	283
Ocean Renewable Power Company	10	33	200	170	42	35	33	28	210	179
Tidal Energy Pty Ltd 1	1.5	1.5	16960	14415	3580	3045	2885	2450	17810	15135
Tidal Energy Pty Ltd 2	2.4	2.4	6357	5403	1341	1140	1080	918	6678	5676
Tidal Energy Pty Ltd 3	5	5	2034	1728	428	364	344	292	2136	1814
Tidal Energy Pty Ltd 4	7	7	1452	1234	306	260	246	208	1524	1296
Tidal Energy Pty Ltd 5	10	10	508	432	106	90	86	73	533	453
Tidal Generation Limited	18.2	18.2	278	237	58	49	46	39	292	249
Tidal Sails AS	10	10	508	432	106	90	86	73	533	453
Tide Tec AS	10	10	508	432	106	90	86	73	533	453
Tocardo BV 1	3.2	3.2	4767	4053	1005	855	810	687	5007	4254
Tocardo BV 2	6.4	6.4	1588	1350	334	284	268	228	1668	1418
Tocardo BV 3	4.6	4.6	2210	1878	466	396	374	318	2322	1972
Tocardo BV 4	9.2	9.2	552	469	116	98	93	79	580	493
Verdant Power Small	5	5	2034	1728	428	364	344	292	2136	1814
Verdant Power Large	10	10	508	432	106	90	86	73	533	453
Voith Hydro Small	13	13	390	332	82	69	66	56	410	348
Voith Hydro Large	16	16	317	269	66	56	53	45	333	283

***) *W_{dev} and L_{dev} are approximated from the supplied data*

*) W_{dev} and L_{dev} are approximated from the supplied data

				Moldefjorden (Crossing # 2)				Voldafjord (Crossing # 4)			
Technology	**W_{dev} (m)**	**L_{dev} (m)**	**N_{down}**	**$N_{cross\_sus/float}$**	**N_{cross_SFT}**	**$N_{tot\_sus/float}$**	**N_{tot_SFT}**	**$N_{cross\_sus/float}$**	**N_{cross_SFT}**	**$N_{tot\_sus/float}$**	**N_{tot_SFT}**
Atlantis Resources Corp	18	18	1	282	239	282	239	59	50	59	50
BioPower Systems Pty Ltd	17	17	1	298	253	298	253	62	53	62	53
Hales Energy Ltd	-	-	-	-	-	-	-	-	-	-	-
Hammerfest Strom Small	20	20	1	253	215	253	215	53	45	53	45
Hammerfest Strom Large	21	21	1	241	205	241	205	50	42	50	42
HPS AS	6	32	2	217	185	434	370	45	39	90	78
Hydro-Gen *)	3.57	3.57	2	1425	1211	2850	2422	300	255	600	510
Kepler Energy	10	120	1	60	51	60	51	12	10	12	10
Nautricity Ltd	14	14	1	362	308	362	308	76	64	76	64
Neptune Renewable Energy Ltd	11	11	1	462	392	462	392	97	82	97	82
Norwegian Ocean Power Small *)	12.65	12.65	1	401	341	401	341	84	71	84	71
Norwegian Ocean Power Large *)	22.36	22.36	1	226	192	226	192	47	40	47	40
Ocean Flow Energy Limited Small *)	5.08	5.08	2	1000	850	2000	1700	210	179	420	358
Ocean Flow Energy Limited Large *)	16.00	16.00	1	317	269	317	269	66	56	66	56
Ocean Renewable Power Company	10	33	1	200	170	200	170	42	35	42	35
Tidal Energy Pty Ltd 1	1.5	1.5	5	3392	2883	16960	14415	716	609	3580	3045
Tidal Energy Pty Ltd 2	2.4	2.4	3	2119	1801	6357	5403	447	380	1341	1140
Tidal Energy Pty Ltd 3	5	5	2	1017	864	2034	1728	214	182	428	364
Tidal Energy Pty Ltd 4	7	7	2	726	617	1452	1234	153	130	306	260
Tidal Energy Pty Ltd 5	10	10	1	508	432	508	432	106	90	106	90
Tidal Generation Limited	18.2	18.2	1	278	237	278	237	58	49	58	49
Tidal Sails AS	10	10	1	508	432	508	432	106	90	106	90
Tide Tec AS	10	10	1	508	432	508	432	106	90	106	90
Tocardo BV 1	3.2	3.2	3	1589	1351	4767	4053	335	285	1005	855
Tocardo BV 2	6.4	6.4	2	794	675	1588	1350	167	142	334	284
Tocardo BV 3	4.6	4.6	2	1105	939	2210	1878	233	198	466	396
Tocardo BV 4	9.2	9.2	1	552	469	552	469	116	98	116	98
Verdant Power Small	5	5	2	1017	864	2034	1728	214	182	428	364
Verdant Power Large	10	10	1	508	432	508	432	106	90	106	90
Voith Hydro Small	13	13	1	390	332	390	332	82	69	82	69
Voith Hydro Large	16	16	1	317	269	317	269	66	56	66	56

Ltot (m)	8034	2014
Wbridge (m)	70	
Lship (m)	200	
Ledge (m)	100	
R others	0	
R tunnel	0.15	

Technology	Nordfjord (Crossing # 5) $N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}	Boknafjord (Crossing # 8) $N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}
Atlantis Resources Corp	47	40	47	40	296	251	296	251
BioPower Systems Pty Ltd	50	42	50	42	313	266	313	266
Hales Energy Ltd	-	-	-	-	-	-	-	-
Hammerfest Strom Small	42	36	42	36	266	226	266	226
Hammerfest Strom Large	40	34	40	34	253	215	253	215
Hammerfest Strom Large	36	31	72	62	228	194	456	388
Hydro-Gen *)	242	205	484	410	1496	1272	2992	2544
Hydro-Gen *)	10	8	10	8	64	54	64	54
Kepler Energy	61	52	61	52	381	323	381	323
Nautricity Ltd	78	66	78	66	485	412	485	412
Norwegian Ocean Power Small *)	67	57	67	57	421	358	421	358
Norwegian Ocean Power Large *)	38	32	38	32	238	202	238	202
Ocean Flow Energy Limited Small *)	169	144	338	288	1050	892	2100	1784
Ocean Flow Energy Limited Large *)	53	45	53	45	333	283	333	283
Norwegian Ocean Power Large *)	33	28	33	28	210	179	210	179
Tidal Energy Pty Ltd 1	577	490	2885	2450	3562	3027	17810	15135
Tidal Energy Pty Ltd 2	360	306	1080	918	2226	1892	6678	5676
Tidal Energy Pty Ltd 3	172	146	344	292	1068	907	2136	1814
Tidal Energy Pty Ltd 4	123	104	246	208	762	648	1524	1296
Tidal Energy Pty Ltd 5	86	73	86	73	533	453	533	453
Ocean Flow Energy Limited Large *)	46	39	46	39	292	249	292	249
Ocean Renewable Power Company	86	73	86	73	533	453	533	453
Tidal Energy Pty Ltd 1	86	73	86	73	533	453	533	453
Tocardo BV 1	270	229	810	687	1669	1418	5007	4254
Tocardo BV 2	134	114	268	228	834	709	1668	1418
Tocardo BV 3	187	159	374	318	1161	986	2322	1972
Tocardo BV 4	93	79	93	79	580	493	580	493
Verdant Power Small	172	146	344	292	1068	907	2136	1814
Verdant Power Large	86	73	86	73	533	453	533	453
Voith Hydro Small	66	56	66	56	410	348	410	348
Voith Hydro Large	53	45	53	45	333	283	333	283
	1700				8416			

Appendix 9: Calculations of the energy from TISEC devices

Table A9:1 Annual energy production for the different technologies and bridging structures for the different fjord crossing locations.

		Moldefjorden (Crossing # 2)		**Voldafjord (Crossing # 4)**		**Nordfjord (Crossing # 5)**		**Boknafjord (Crossing # 8)**	
Technology	**P_{rated} (kW)**	**$E_{sus/float}$ (GWh/yr)**	**E_{SFT} (GWh/yr)**	**$E_{sus/float}$ (GWh/yr)**	**E_{SFT} (GWh/yr)**	**$E_{sus/float}$ (GWh/yr)**	**E_{SFT} (GWh/yr)**	**$E_{sus/float}$ (GWh/yr)**	**E_{SFT} (GWh/yr)**
Atlantis Resources Corp	1000	988	837	207	175	165	140	1037	880
BioPower Systems Pty Ltd	250	261	222	54	46	44	37	274	233
Hales Energy Ltd	-	-	-	-	-	-	-	-	-
Hammerfest Strom Small	300	266	226	56	47	44	38	280	238
Hammerfest Strom Large	1000	844	718	175	147	140	119	887	753
HPS AS	1000	1521	1296	315	273	252	217	1598	1360
Hydro-Gen	40	399	339	84	71	68	57	419	357
Kepler Energy	4600	967	822	193	161	161	129	1032	870
Nautricity Ltd	500	634	540	133	112	107	91	668	566
Neptune Renewable Energy Ltd	400	648	549	136	115	109	93	680	577
Norwegian Ocean Power Small	600	843	717	177	149	141	120	885	753
Norwegian Ocean Power Large	2500	1980	1682	412	350	333	280	2085	1770
Ocean Flow Energy Limited Small	35	245	208	52	44	41	35	258	219
Ocean Flow Energy Limited Large	1000	1111	943	231	196	186	158	1167	992
Ocean Renewable Power Company	180	126	107	26	22	21	18	132	113
Tidal Energy Pty Ltd 1	120	7131	6061	1505	1280	1213	1030	7489	6364
Tidal Energy Pty Ltd 2	300	6682	5680	1410	1198	1135	965	7020	5967
Tidal Energy Pty Ltd 3	1300	9265	7871	1950	1658	1567	1330	9730	8263
Tidal Energy Pty Ltd 4	2700	13737	11675	2895	2460	2327	1968	14418	12261
Tidal Energy Pty Ltd 5	5500	9790	8326	2043	1734	1657	1407	10272	8730
Tidal Generation Limited	1000	974	830	203	172	161	137	1023	872
Tidal Sails AS	1000 0	17800	15137	3714	3154	3013	2558	18676	15873
Tide Tec AS	-	-	-	-	-	-	-	-	-
Tocardo BV 1	86	1437	1221	303	258	244	207	1509	1282
Tocardo BV 2	43	239	203	50	43	40	34	251	214
Tocardo BV 3	174	1347	1145	284	241	228	194	1416	1202
Tocardo BV 4	87	168	143	35	30	28	24	177	150
Verdant Power Small	85	606	515	127	108	102	87	636	540
Verdant Power Large	500	890	757	186	158	151	128	934	794
Voith Hydro Small	1000	1367	1163	287	242	231	196	1437	1219
Voith Hydro Large	1000	1111	943	231	196	186	158	1167	992
Min Energy (GWh/yr)	-	126	107	26	22	21	18	132	113
Max Energy (GWh/yr)	-	17800	15137	3714	3154	3013	2558	18676	15873
Average Energy (GWh/yr)	-	2875	2444	603	512	486	412	3019	2566
1000s of Homes Powered	-	575	489	121	102	97	82	604	513

Appendix 10: Calculations of the number of WEC devices

Table A10:1 Number of WEC devices for the different fjord crossing locations for a suspension bridge or floating bridge design ($N_{tot\_sus/float}$).

Technology	**W_{space} (m)**	**1**	**2**	**3**	**4**	**5**	**6**	**7a**	**7b**	**8**
Applied Technologies Company Ltd	Varies	-	-	-	-	-	-	-	-	-
AquaGen Technologies	15	470	2535	995	530	425	1130	395	1770	2665
Atargis Energy Corporation	0	-	-	-	-	-	-	-	-	-
Atmocean	30	138	759	297	156	126	336	117	528	798
BioPower Systems Pty Ltd	100	13	75	29	15	12	33	11	52	79
Hann-Ocean Energy Pte Ltd	50	54	302	118	62	50	134	46	210	318
MotorWave group *)	7	203	1089	427	229	184	486	170	760	1144
Ocean Energy Industries, Inc.	?	-	-	-	-	-	-	-	-	-
Ocean Harvesting Technologies AB	50	54	302	118	62	50	134	46	210	318
OWWE - INNOVAKO Floating Bridge	?	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO OWWE-Rig	Varies	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO Wave Pump-Rig	Varies	-	-	-	-	-	-	-	-	-
OWECO Ocean Wave Energy Company 1	5.51	3354	17992	7059	3783	3042	8021	2808	12558	18889
OWECO Ocean Wave Energy Company 2	10.93	903	4879	1911	1022	819	2170	756	3402	5124
OWECO Ocean Wave Energy Company 3	22	252	1384	540	288	232	616	212	964	1452
Oceanlinx Ltd	Varies	-	-	-	-	-	-	-	-	-
PerpetuWave Power Pty Ltd	40	68	378	148	78	62	168	58	264	398
RESEN ENERGY	60	44	252	98	50	40	110	38	174	264
Sea Power Ltd	450	2	15	5	2	1	6	1	10	16
Seatricity	30	138	759	297	156	126	336	117	528	798
Seawood Designs Inc	32	129	711	276	147	117	315	108	495	747
Trident Energy Ltd	Varies	-	-	-	-	-	-	-	-	-
Vigor Wave Energy AB	100	13	75	29	15	12	33	11	52	79
Voith Hydro Wavegen	Varies	-	-	-	-	-	-	-	-	-
Waveenergyfyn	30	46	253	99	52	42	112	39	176	266
Wavestar A/S	?	-	-	-	-	-	-	-	-	-
WavePiston ApS	35	39	217	84	45	36	96	33	151	228
W4P Waves4Power AB	35	117	651	252	135	108	288	99	453	684
Wello Ltd.	100	13	75	29	15	12	33	11	52	79

***)** *W_{dev} and L_{dev} are approximated from the supplied data*

Table A10:2 Number of WEC devices for the different fjord crossing locations for a submerged floating tunnel design (N_{tot_SFT}).

Technology	**W_{space} (m)**	**1**	**2**	**3**	**4**	**5**	**6**	**7a**	**7b**	**8**
Applied Technologies Company Ltd	Varies	-	-	-	-	-	-	-	-	-
AquaGen Technologies	15	400	2155	845	450	360	960	335	1505	2265
Atargis Energy Corporation	0	-	-	-	-	-	-	-	-	-
Atmocean	30	117	645	252	132	105	285	99	450	678
BioPower Systems Pty Ltd	100	11	64	24	12	10	28	9	44	67
Hann-Ocean Energy Pte Ltd	50	46	256	100	52	42	114	38	178	270
MotorWave group *)	7	172	926	363	195	157	413	144	646	972
Ocean Energy Industries, Inc.	?	-	-	-	-	-	-	-	-	-
Ocean Harvesting Technologies AB	50	46	256	100	52	42	114	38	178	270
OWWE - INNOVAKO Floating Bridge	?	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO OWWE-Rig	Varies	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO Wave Pump-Rig	Varies	-	-	-	-	-	-	-	-	-
OWECO Ocean Wave Energy Company 1	5.51	2847	15288	5993	3224	2587	6825	2392	10673	16055
OWECO Ocean Wave Energy Company 2	10.93	770	4144	1624	868	700	1848	644	2891	4354
OWECO Ocean Wave Energy Company 3	22	216	1176	460	244	196	520	180	820	1232
Oceanlinx Ltd	Varies	-	-	-	-	-	-	-	-	-
PerpetuWave Power Pty Ltd	40	58	322	124	66	52	142	48	224	338
RESEN ENERGY	60	38	214	82	44	34	94	32	148	224
Sea Power Ltd	450	1	13	4	2	1	5	1	9	14
Seatricity	30	117	645	252	132	105	285	99	450	678
Seawood Designs Inc	32	111	603	234	126	99	267	93	420	636
Trident Energy Ltd	Varies	-	-	-	-	-	-	-	-	-
Vigor Wave Energy AB	100	11	64	24	12	10	28	9	44	67
Voith Hydro Wavegen	Varies	-	-	-	-	-	-	-	-	-
Waveenergyfyn	30	39	215	84	44	35	95	33	150	226
Wavestar A/S	?	-	-	-	-	-	-	-	-	-
WavePiston ApS	35	33	184	72	38	30	81	28	128	193
W4P Waves4Power AB	35	99	552	216	114	90	243	84	384	579
Wello Ltd.	100	11	64	24	12	10	28	9	44	67

***)** *W_{dev} and L_{dev} are approximated from the supplied data*

*) W_{space} is approximated from the supplied data

Technology	W_{space} (m)	N_{down}	Halsafjord (Crossing # 1) $N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}	Moldefjord (Crossing # 2) $N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}
Applied Technologies Company Ltd	Varies	-	-	-	-	-	-	-	-	-
AquaGen Technologies	15	5	94	80	470	400	507	431	2535	2155
Atargis Energy Corporation	0	-	-	-	-	-	-	-	-	-
Atmocean	30	3	46	39	138	117	253	215	759	645
BioPower Systems Pty Ltd	100	1	13	11	13	11	75	64	75	64
Hann-Ocean Energy Pte Ltd	50	2	27	23	54	46	151	128	302	256
MotorWave group *)	7	1	203	172	203	172	1089	926	1089	926
Ocean Energy Industries, Inc.	Varies	-	-	-	-	-	-	-	-	-
Ocean Harvesting Technologies AB	50	2	27	23	54	46	151	128	302	256
OWWE - INNOVAKO Floating Bridge	Unknown	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO OWWE-Rig	Varies	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO Wave Pump-Rig	Varies	-	-	-	-	-	-	-	-	-
OWECO Ocean Wave Energy Company 1	5.51	13	258	219	3354	2847	1384	1176	17992	15288
OWECO Ocean Wave Energy Company 2	10.93	7	129	110	903	770	697	592	4879	4144
OWECO Ocean Wave Energy Company 3	22	4	63	54	252	216	346	294	1384	1176
Oceanlinx Ltd	Varies	-	-	-	-	-	-	-	-	-
PerpetuWave Power Pty Ltd	40	2	34	29	68	58	189	161	378	322
RESEN ENERGY	60	2	22	19	44	38	126	107	252	214
Sea Power Ltd	450	1	2	1	2	1	15	13	15	13
Seatricity	30	3	46	39	138	117	253	215	759	645
Seawood Designs Inc	32	3	43	37	129	111	237	201	711	603
Trident Energy Ltd	Varies	-	-	-	-	-	-	-	-	-
Vigor Wave Energy AB	100	1	13	11	13	11	75	64	75	64
Voith Hydro Wavegen	Varies	-	-	-	-	-	-	-	-	-
Waveenergyfyn	30	1	46	39	46	39	253	215	253	215
Wavestar A/S	Unknown	-	-	-	-	-	-	-	-	-
WavePiston ApS	35	1	39	33	39	33	217	184	217	184
W4P Waves4Power AB	35	3	39	33	117	99	217	184	651	552
Wello Ltd.	100	1	13	11	13	11	75	64	75	64

Ltot (m)	1829
Wbridge (m)	70
Lship (m)	200
Ledge (m)	100
R others	0
R tunnel	0.15

8034

	Storfjord (Crossing # 3)				Voldafjord (Crossing # 4)				Nordfjord (Crossing # 5)			
Technology	$N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}	$N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}	$N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}
Applied Technologies Company Ltd	-	-	-	-	-	-	-	-	-	-	-	-
AquaGen Technologies	199	169	995	845	106	90	530	450	85	72	425	360
Atargis Energy Corporation	-	-	-	-	-	-	-	-	-	-	-	-
Atmocean	99	84	297	252	52	44	156	132	42	35	126	105
BioPower Systems Pty Ltd	29	24	29	24	15	12	15	12	12	10	12	10
Hann-Ocean Energy Pte Ltd	59	50	118	100	31	26	62	52	25	21	50	42
MotorWave group *)	427	363	427	363	229	195	229	195	184	157	184	157
Ocean Energy Industries, Inc.	-	-	-	-	-	-	-	-	-	-	-	-
Ocean Harvesting Technologies AB	59	50	118	100	31	26	62	52	25	21	50	42
OWWE - INNOVAKO Floating Bridge	-	-	-	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO OWWE-Rig	-	-	-	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO Wave Pump-Rig	-	-	-	-	-	-	-	-	-	-	-	-
OWECO Ocean Wave Energy Company 1	543	461	7059	5993	291	248	3783	3224	234	199	3042	2587
OWECO Ocean Wave Energy Company 2	273	232	1911	1624	146	124	1022	868	117	100	819	700
OWECO Ocean Wave Energy Company 3	135	115	540	460	72	61	288	244	58	49	232	196
Oceanlinx Ltd	-	-	-	-	-	-	-	-	-	-	-	-
PerpetuWave Power Pty Ltd	74	62	148	124	39	33	78	66	31	26	62	52
RESEN ENERGY	49	41	98	82	25	22	50	44	20	17	40	34
Sea Power Ltd	5	4	5	4	2	2	2	2	1	1	1	1
Seatricity	99	84	297	252	52	44	156	132	42	35	126	105
Seawood Designs Inc	92	78	276	234	49	42	147	126	39	33	117	99
Trident Energy Ltd	-	-	-	-	-	-	-	-	-	-	-	-
Vigor Wave Energy AB	29	24	29	24	15	12	15	12	12	10	12	10
Voith Hydro Wavegen	-	-	-	-	-	-	-	-	-	-	-	-
Waveenergyfyn	99	84	99	84	52	44	52	44	42	35	42	35
Wavestar A/S	-	-	-	-	-	-	-	-	-	-	-	-
WavePiston ApS	84	72	84	72	45	38	45	38	36	30	36	30
W4P Waves4Power AB	84	72	252	216	45	38	135	114	36	30	108	90
Wello Ltd.	29	24	29	24	15	12	15	12	12	10	12	10
	3400				2014				1700			

Technology	Sognefjord (Crossing # 6)				Bjørnafjord a (Crossing # 7a)				Bjørnafjord b (Crossing # 7b)			
	$N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}	$N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}	$N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}
Applied Technologies Company Ltd	-	-	-	-	-	-	-	-	-	-	-	-
AquaGen Technologies	226	192	1130	960	79	67	395	335	354	301	1770	1505
Atargis Energy Corporation	-	-	-	-	-	-	-	-	-	-	-	-
Atmocean	112	95	336	285	39	33	117	99	176	150	528	450
BioPower Systems Pty Ltd	33	28	33	28	11	9	11	9	52	44	52	44
Hann-Ocean Energy Pte Ltd	67	57	134	114	23	19	46	38	105	89	210	178
MotorWave group *)	486	413	486	413	170	144	170	144	760	646	760	646
Ocean Energy Industries, Inc.	-	-	-	-	-	-	-	-	-	-	-	-
Ocean Harvesting Technologies AB	67	57	134	114	23	19	46	38	105	89	210	178
OWWE - INNOVAKO Floating Bridge	-	-	-	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO OWWE-Rig	-	-	-	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO Wave Pump-Rig	-	-	-	-	-	-	-	-	-	-	-	-
OWECO Ocean Wave Energy Company 1	617	525	8021	6825	216	184	2808	2392	966	821	12558	10673
OWECO Ocean Wave Energy Company 2	310	264	2170	1848	108	92	756	644	486	413	3402	2891
OWECO Ocean Wave Energy Company 3	154	130	616	520	53	45	212	180	241	205	964	820
Oceanlinx Ltd	-	-	-	-	-	-	-	-	-	-	-	-
PerpetuWave Power Pty Ltd	84	71	168	142	29	24	58	48	132	112	264	224
RESEN ENERGY	55	47	110	94	19	16	38	32	87	74	174	148
Sea Power Ltd	6	5	6	5	1	1	1	1	10	9	10	9
Seatricity	112	95	336	285	39	33	117	99	176	150	528	450
Seawood Designs Inc	105	89	315	267	36	31	108	93	165	140	495	420
Trident Energy Ltd	-	-	-	-	-	-	-	-	-	-	-	-
Vigor Wave Energy AB	33	28	33	28	11	9	11	9	52	44	52	44
Voith Hydro Wavegen	-	-	-	-	-	-	-	-	-	-	-	-
Waveenergyfyn	112	95	112	95	39	33	39	33	176	150	176	150
Wavestar A/S	-	-	-	-	-	-	-	-	-	-	-	-
WavePiston ApS	96	81	96	81	33	28	33	28	151	128	151	128
W4P Waves4Power AB	96	81	288	243	33	28	99	84	151	128	453	384
Wello Ltd.	33	28	33	28	11	9	11	9	52	44	52	44
	3810				1600				5732			

	Boknafjord (Crossing # 8)			
Technology	$N_{cross\_sus/float}$	N_{cross_SFT}	$N_{tot\_sus/float}$	N_{tot_SFT}
Applied Technologies Company Ltd	-	-	-	-
AquaGen Technologies	533	453	2665	2265
Atargis Energy Corporation	-	-	-	-
Atmocean	266	226	798	678
BioPower Systems Pty Ltd	79	67	79	67
Hann-Ocean Energy Pte Ltd	159	135	318	270
MotorWave group *)	1144	972	1144	972
Ocean Energy Industries, Inc.	-	-	-	-
Ocean Harvesting Technologies AB	159	135	318	270
OWWE - INNOVAKO Floating Bridge	-	-	-	-
OWWE - INNOVAKO OWWE-Rig	-	-	-	-
OWWE - INNOVAKO Wave Pump-Rig	-	-	-	-
OWECO Ocean Wave Energy Company 1	1453	1235	18889	16055
OWECO Ocean Wave Energy Company 2	732	622	5124	4354
OWECO Ocean Wave Energy Company 3	363	308	1452	1232
Oceanlinx Ltd	-	-	-	-
PerpetuWave Power Pty Ltd	199	169	398	338
RESEN ENERGY	132	112	264	224
Sea Power Ltd	16	14	16	14
Seatricity	266	226	798	678
Seawood Designs Inc	249	212	747	636
Trident Energy Ltd	-	-	-	-
Vigor Wave Energy AB	79	67	79	67
Voith Hydro Wavegen	-	-	-	-
Waveenergyfyn	266	226	266	226
Wavestar A/S	-	-	-	-
WavePiston ApS	228	193	228	193
W4P Waves4Power AB	228	193	684	579
Wello Ltd.	79	67	79	67
	8416			

Appendix 11: Calculations of the energy from WEC devices

Table A11:1 Annual energy production for the different fjord crossings for a suspension bridge or floating bridge design ($E_{sus/float}$).

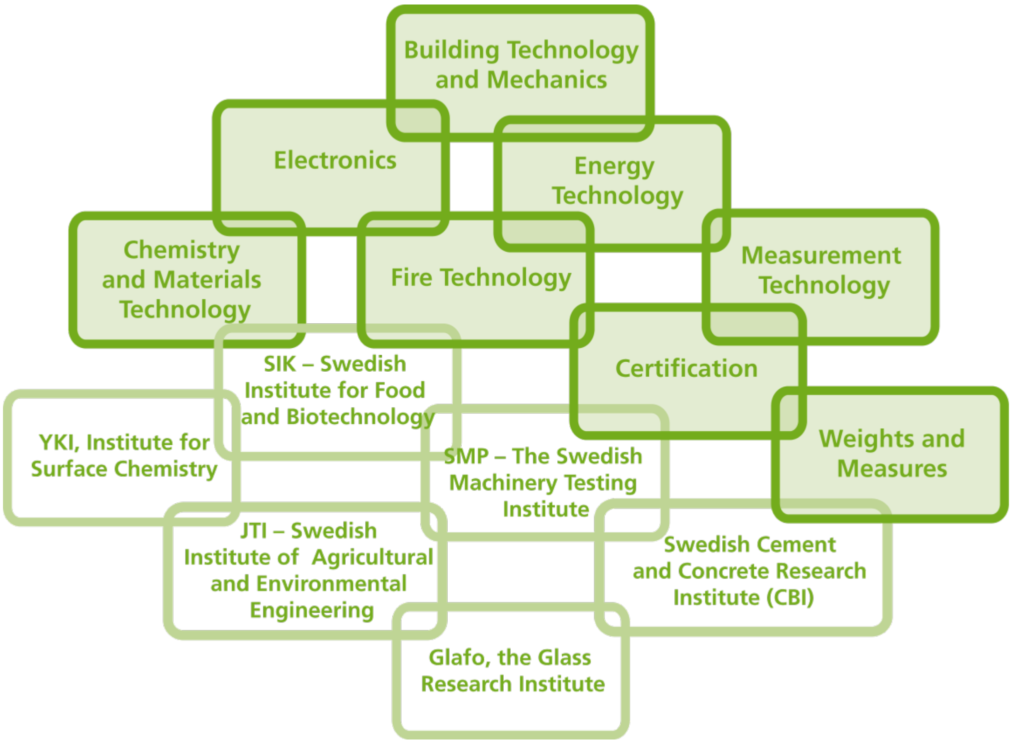
Technology	P_{rated} (kW)	1	2	3	4	5	6	7a	7b	8
Applied Technologies Company Ltd	10-12000	-	-	-	-	-	-	-	-	-
AquaGen Technologies	100	165	888	349	186	149	396	138	620	934
Atargis Energy Corporation	5000	-	-	-	-	-	-	-	-	-
Atmocean	20	10	53	21	11	9	24	8	37	56
BioPower Systems Pty Ltd	1000	46	263	102	53	42	116	39	182	277
Hann-Ocean Energy Pte Ltd	1000	189	1058	413	217	175	470	161	736	1114
MotorWave group	16	11	61	24	13	10	27	10	43	64
Ocean Energy Industries, Inc.	0.5-10000	-	-	-	-	-	-	-	-	-
Ocean Harvesting Technologies AB	150	28	159	62	33	26	70	24	110	167
OWWE - INNOVAKO Floating Bridge	-	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO OWWE-Rig	5000	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO Wave Pump-Rig	-	-	-	-	-	-	-	-	-	-
OWECO Ocean Wave Energy Company 1	30	353	1891	742	398	320	843	295	1320	1986
OWECO Ocean Wave Energy Company 2	250	791	4274	1674	895	717	1901	662	2980	4489
OWECO Ocean Wave Energy Company 3	2150	1898	10427	4068	2170	1748	4641	1597	7262	10939
Oceanlinx Ltd	500-2500	-	-	-	-	-	-	-	-	-
PerpetuWave Power Pty Ltd	850	203	1126	441	232	185	500	173	786	1185
RESEN ENERGY	300	46	265	103	53	42	116	40	183	278
Sea Power Ltd	3750	26	197	66	26	13	79	13	131	210
Seatricity	30	15	80	31	16	13	35	12	56	84
Seawood Designs Inc	300	136	747	290	155	123	331	114	520	785
Trident Energy Ltd	40-150	-	-	-	-	-	-	-	-	-
Vigor Wave Energy AB	100000	4555	26280	10162	5256	4205	11563	3854	18221	27682
Voith Hydro Wavegen	18.5-132	-	-	-	-	-	-	-	-	-
Waveenergyfyn	200	32	177	69	36	29	78	27	123	186
Wavestar A/S	600	-	-	-	-	-	-	-	-	-
WavePiston ApS	100	14	76	29	16	13	34	12	53	80
W4P Waves4Power AB	250	102	570	221	118	95	252	87	397	599
Wello Ltd.	1000	46	263	102	53	42	116	39	182	277
Min Energy (GWh/yr)	-	10	53	21	11	9	24	8	37	56
Max Energy (GWh/yr)	-	4555	26280	10162	5256	4205	11563	3854	18221	27682
Average Energy (GWh/yr)	-	456	2571	998	523	419	1136	384	1786	2705
1000s of Homes Powered	-	91	514	200	105	84	227	77	357	541

Table A11:2 Annual energy production for the different fjord crossings for a submerged floating tunnel design (E_{SFT}).

Technology	P_{rated} (kW)	1	2	3	4	5	6	7a	7b	8
Applied Technologies Company Ltd	10-12000	-	-	-	-	-	-	-	-	-
AquaGen Technologies	100	140	755	296	158	126	336	117	527	794
Atargis Energy Corporation	5000	-	-	-	-	-	-	-	-	-
Atmocean	20	8	45	18	9	7	20	7	32	48
BioPower Systems Pty Ltd	1000	39	224	84	42	35	98	32	154	235
Hann-Ocean Energy Pte Ltd	1000	161	897	350	182	147	399	133	624	946
MotorWave group *)	16	10	52	20	11	9	23	8	36	54
Ocean Energy Industries, Inc.	0.5-10000	-	-	-	-	-	-	-	-	-
Ocean Harvesting Technologies AB	150	24	135	53	27	22	60	20	94	142
OWWE - INNOVAKO Floating Bridge	-	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO OWWE-Rig	5000	-	-	-	-	-	-	-	-	-
OWWE - INNOVAKO Wave Pump-Rig	-	-	-	-	-	-	-	-	-	-
OWECO Ocean Wave Energy Company 1	30	299	1607	630	339	272	717	251	1122	1688
OWECO Ocean Wave Energy Company 2	250	675	3630	1423	760	613	1619	564	2533	3814
OWECO Ocean Wave Energy Company 3	2150	1627	8860	3465	1838	1477	3917	1356	6178	9281
Oceanlinx Ltd	500-2500	-	-	-	-	-	-	-	-	-
PerpetuWave Power Pty Ltd	850	173	959	369	197	155	423	143	667	1007
RESEN ENERGY	300	40	225	86	46	36	99	34	156	235
Sea Power Ltd	3750	13	171	53	26	13	66	13	118	184
Seatricity	30	12	68	26	14	11	30	10	47	71
Seawood Designs Inc	300	117	634	246	132	104	281	98	442	669
Trident Energy Ltd	40-150	-	-	-	-	-	-	-	-	-
Vigor Wave Energy AB	100000	3854	22426	8410	4205	3504	9811	3154	15418	23477
Voith Hydro Wavegen	18.5-132	-	-	-	-	-	-	-	-	-
Waveenergyfyn	200	27	151	59	31	25	67	23	105	158
Wavestar A/S	600	-	-	-	-	-	-	-	-	-
WavePiston ApS	100	12	64	25	13	11	28	10	45	68
W4P Waves4Power AB	250	87	484	189	100	79	213	74	336	507
Wello Ltd.	1000	39	224	84	42	35	98	32	154	235
Min Energy (GWh/yr)	-	8	45	18	9	7	20	7	32	48
Max Energy (GWh/yr)	-	3854	22426	8410	4205	3504	9811	3154	15418	23477
Average Energy (GWh/yr)	-	387	2190	836	430	352	963	320	1515	2295
1000s of Homes Powered	-	77	438	167	86	70	193	64	303	459

SP Technical Research Institute of Sweden

Our work is concentrated on innovation and the development of value-adding technology. Using Sweden's most extensive and advanced resources for technical evaluation, measurement technology, research and development, we make an important contribution to the competitiveness and sustainable development of industry. Research is carried out in close conjunction with universities and institutes of technology, to the benefit of a customer base of about 9000 organisations, ranging from start-up companies developing new technologies or new ideas to international groups.



SP Technical Research Institute of Sweden
Box 857, SE-501 15 BORÅS, SWEDEN
Telephone: +46 10 516 50 00, Telefax: +46 33 13 55 02
E-mail: info@sp.se, Internet: www.sp.se
www.sp.se

SP Structural and Solid Mechanics
SP Arbetsrapport :2012:06
ISBN
ISSN 0284-5172

More information about publications published by SP: **www.sp.se/publ**

Statens vegvesen

Statens vegvesen
Vegdirektoratet
Publikasjonsekspedisjonen
Postboks 8142 Dep
0033 OSLO
Tlf: (+47 915) 02030
publvd@vegvesen.no

ISSN: 1893-1162