Assess the Design/Inspection Criteria/Standards for Wave and/or Current Energy Generating Devices

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PART IV – RESULTS

PART I – EXECUTIVE SUMMARY

The Minerals Management Service (MMS) contracted with Free Flow Energy – an engineering services firm focused exclusively on new technology hydrokinetics – to assess the design and inspection criteria and standards for wave and current energy-generating devices. Focusing on wave and current energy conversion equipment and their supporting systems, Free Flow Energy reviewed the current technologies, reviewed engineering standards, reviewed existing inspection and monitoring approaches and technologies, described safety and regulatory concerns, performed a gap analysis, recommended research initiatives, and provided comments to the MMS Potential Incident of NonCompliance (PINC) list.

Chapter 1. Conclusions

From comprehensive research of wave and current energy conversion – the industry, the technologies, and current engineering standards and regulations – with a focus on the Outer Continental Shelf (OCS), Free Flow Energy offers the following conclusions:

- **State of the industry** As most familiar with the industry would acknowledge, wave and current energy conversion is a nascent industry with many stakeholders, many technologies, and many uncertainties.

- **Industry participants** A distinction must be made between *site developers* and *technology developers*, and within these groups, the technical, financial, and managerial capabilities of the various players should be ascertained. At present, this information is not always apparent. Technology companies pursuing site development as a means of marketing their technology may be ill equipped to do so. Likewise, site developers with little or no technological know-how often boast unproven technologies as a means of gaining interest in their site proposals.

- **Energy conversion devices** The designs of wave and current energy conversion devices suitable for OCS implementation are quite uncertain at this juncture. Since wave and current energy conversion devices exhibit varying dynamical behavior and structural requisites, the establishment of one or even several applications of engineering principles might be insufficient to ensure compliance with installation, operation, maintenance, and decommissioning specifications.

- **Energy conversions systems** Viable alternative energy conversion requires a system, not simply an energy conversion device. In addition to supporting structures, anchors, and moorings, other components in an OCS wave or current energy conversion system might include control systems, transmission equipment, and grid interconnection apparatus, as well as shore-based support industry.

- **Electrical transmission** Electrical transmission is emerging as a pivotal issue in the success of offshore wave and current energy conversion. The cost of subsea transmission cable and the cost of cable installation – estimated at $5 million per mile – will significantly limit development on the OCS unless new technologies and/or methods for manufacturing and installation are developed, and/or subsidies are granted to assist in developing this electrical infrastructure. Additionally, at present the interface of wave and current devices to the subsea transmission network presents some technical challenges.

- **Engineering standards – gaps** Although standards organizations are developing engineering standards for marine energy conversion, only a few engineering standards have been specifically written for wave and current facilities, equipment, and operations. Also, because of the dramatic variance of technologies being considered for marine energy conversion, some standards lack necessary specificity, weakening their effectiveness.

- **Engineering standards – lack of awareness** Many developers have a low awareness and understanding of engineering standards and/or avoid standards because of their lack of specificity. To avoid confusion and to increase compliance, one set of standards should be applied to the global wave and current industry. This action will require increased collaboration among international stakeholders and regulators, but it will greatly benefit the advance of this industry in the U.S. and its territories.

- **Impact of existing oil and gas industry** Areas of overlap between renewable energy conversion and existing oil and gas industries do exist. Similarities can be exploited, but relying heavily on oil and gas standards for the renewable energy industry can further exacerbate the lack of specificity in standards development.

- **OCS development** Most device and site developers are not targeting the OCS. The OCS wave and current energy conversion industry most likely will develop quite narrowly, especially with regard to current energy conversion. An impartial assessment of ocean energy resources on the OCS would benefit the advancement of offshore wave and current energy conversion development.

- **Desirable sites** In addition to adequate wave activity and/or flow velocity, the most suitable sites for wave and current energy conversion will have one or more of the following conditions: a deregulated power market, high electrical kilowatt hour rates, limited electrical power availability from traditional means, strong renewable energy incentives, and/or an existing electrical infrastructure.

- **Regulations** Properly developed regulations can advance the industry by guiding the design, construction, operation, monitoring, inspection, safety and, ultimately, decommissioning of wave and current energy conversion equipment, systems, and facilities.

Chapter 2. Recommendations

To facilitate the implementation of wave and current energy conversion facilities on the U.S. Outer Continental Shelf (OCS) for the benefit of the United States and without compromising safety or performance, Free Flow Energy recommends:

- **Inspection and monitoring** Wave and current energy generation primarily will be remotely controlled and monitored. Additionally, this industry will be deployed in both state and federally-controlled waters. Consequently, it is in the best interests of industry, the regulators, and the public that the inspection of this industry be performed in a consistent manner.

- **Collaboration with FERC** MMS should take the lead in developing a Memorandum of Understanding with the Federal Energy Regulatory Commission (FERC) that promotes a collaborative relationship to (a) maximize the efficiency and effectiveness of MMS and FERC with regard to wave and current energy conversion facility inspection and monitoring, (b) minimize overlap, (c) ensure consistent policy, (d) help advance the emerging marine energy industry, and (e) support and strengthens federal renewable energy initiatives

- **Scientific and technical committees** MMS should develop and/or join scientific and technical committees specific to developing engineering standards for the ocean energy industry so MMS representatives are directly engage in interagency and international efforts.

- **Stakeholder involvement** MMS should assume a leadership role in working with the many stakeholders in offshore energy conversion activities.

- **International involvement** Increase U.S. involvement in international activities to define, develop, and regulate the ocean energy industry – including federal government funding to encourage the participation of public and private experts in the U.S. Not only will international coordination and cooperation facilitate the growth of renewable energy conversion, it will help ensure that U.S. regulations are consistent with the participants globally.

PART II – PROJECT OVERVIEW

Chapter 3. Wave and Current Energy Industry Highlights

3.1 Emerging Technologies, Global Players

For both wave- and current-driven energy systems, a wide range of technology presently exists to harness this renewable resource for the generation of electricity. Although in 2009 one could accurately characterize the ocean energy industry as nascent, much of the technology is not new. As shown in exhibit 3-1, engineers, entrepreneurs, and other visionaries have tried to harness ocean energy since the 1800s.

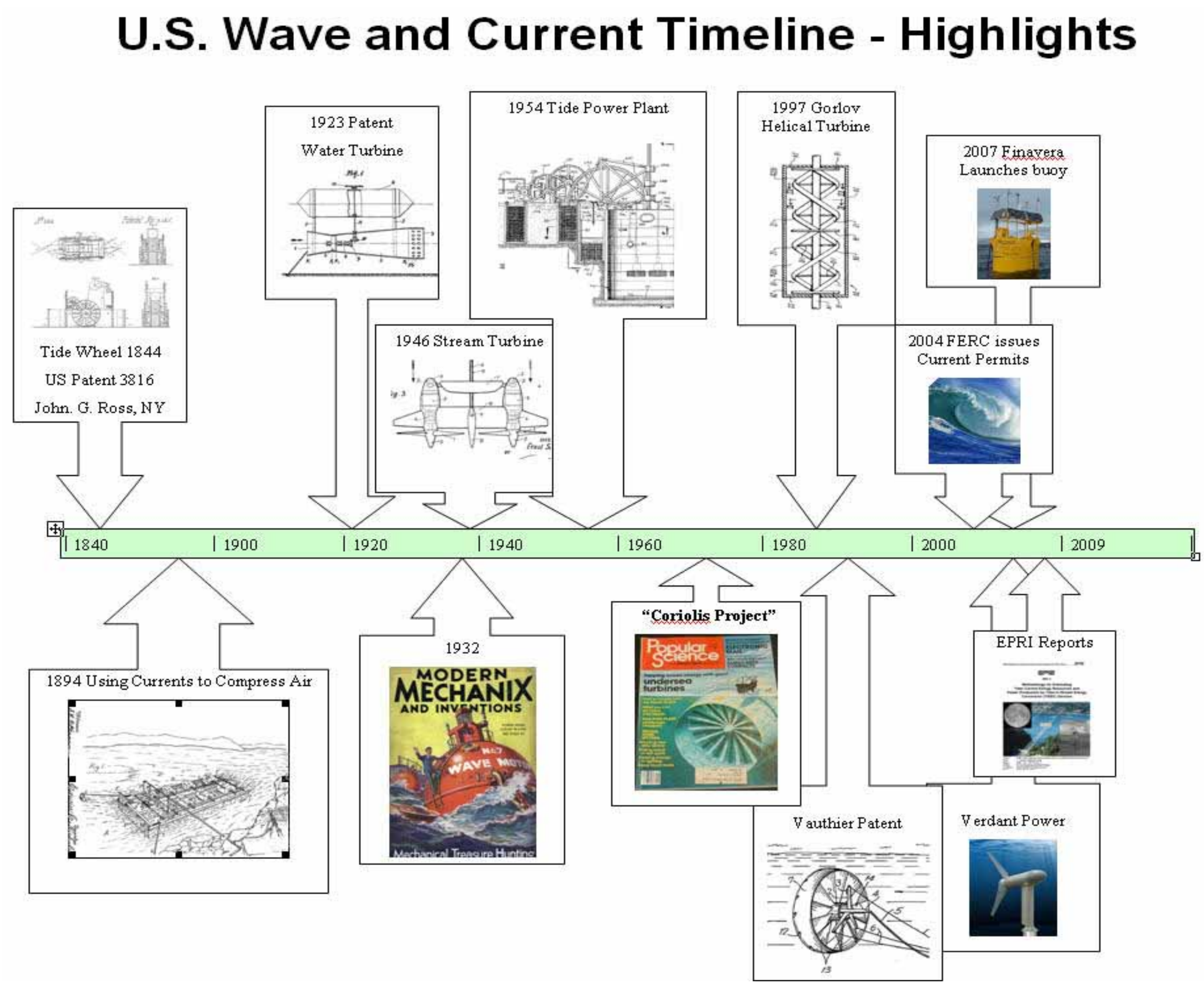

Exhibit 3-1. Historical events in timeline of U.S. current- and wave-energy conversion.[1]

[1] Free Flow Energy, 2009.

Although technology development spans more than a century, no definitive designs have emerged. A very broad range of electromechanical devices are in the early stages of design and development – from surface-deployed attenuation systems to fully-submerged point-absorbing systems for wave energy conversion, and a wide spectrum of turbine-based technologies for current energy conversion. Despite the array of technologies under investigation, only a relatively small number have actually been built, tank tested, and demonstrated.

Funding in the form of grants to support the research development of wave and current technologies is only now beginning to become available. Furthermore, the investment community appears to be awaiting the results of meaningful demonstration testing, proof of concept, and an indication of the fiscal efficacy – and physical survivability – of technologies prior to committing substantial capital investment. The development and application of technologies will, of course, depend upon the availability of such resources. The U.S. Department of Energy has only recently provided funding for the development of advanced water-power projects – including support for the development of in-water testing and development, best siting practices, the assessment of navigational and environmental impacts, and the creation of National Marine Renewable Energy Centers.

Although U.S. Outer Continental Shelf (OCS) waters are regulated by the Minerals Management Service, the stakeholders involved in ocean energy development on the OCS and the energy conversion devices installed in OCS waters might not be U.S.-based. Europe, for instance, a leader in the marine equipment industry with more ocean energy experience than the United States, likely will be involved in OCS projects (although the equipment used by European companies might be fabricated in the Far East) (European Marine Equipment Council 2008). Wave and current energy conversion truly is a global endeavor with international ramifications.

When considering the participants in energy conversion efforts on the OCS, one should not overlook the existing, credible marine engineering industry. Although members of this industry may not be promoting themselves as players in ocean energy, many organizations in the marine engineering industry offer considerable technological expertise relevant to wave and current energy conversion, and their involvement should be of considerable value.

Leading device manufacturers typically have several key factors in their favor:

- Access to substantial financial resources.
- Particularly good sites (which may not be representative of the resource).
- An organizational structure capable of bringing together all of the elements necessary for success: technical, professional, regulatory, and environmental.

The few who might be termed “front runners” have been well publicized, yet in the absence of verifiable data it would be inappropriate to attempt to quantify the success of these leaders in the context of this research. Several technologies sited in particularly good resources do show promise, continue to be tested, and are receiving the financial support required. It is noteworthy to point out, however, that a number of completed demonstration projects have already been decommissioned and the technologies shelved.

3.2 Potential

Figures cited for the potential for ocean energy – tidal, wave, and current energy conversion – have a wide and in some cases dramatic variance. Greentech Media, for instance, points to a possible gigawatt of installed capacity and a $500 million market by 2014 (Englander and Bradford 2008). Extracting meaningful estimates for the potential of wave and current energy conversion on the U.S. Outer Continental Shelf (OCS) can be quite challenging.

The most promising estimates for U.S. wave-energy conversion reflect analysis of Hawaii and West Coast near-shore sites, which, like sites adjacent to the European coast, benefit from strong prevailing winds, ocean storm swell, and ocean currents. Development of wave energy conversion on the OCS has added levels of complexity due to geophysical constraints, added transmission costs, and a depth limitation that may hinder development.

U.S. OCS current energy conversion may be limited to the Gulf Stream off the Florida coast, although the Gulf of Mexico may also prove to be a desirable location if the sea floor topography accelerates flow to an acceptable level. Interest in current energy conversion (which includes tidal energy conversion) is focused on constrictions and curves in inland and near-coastal rivers and waterways.

Commercialization of wave and current technologies is most likely to occur in high-value areas where costly long-distance power transmission to an existing electric-utility grid is not necessary. Early installations, for example, could be to power offshore oil and gas operations, rural electrification (e.g., island communities), military undersea projects, and remote environmental sensing devices. Some wave energy conversion system developers are studying the feasibility of installing their conversion equipment with existing offshore platforms.[2]

Large-scale implementation of offshore energy conversion technologies will be necessary to provide “meaningful” power to the grid. As with offshore oil and gas facilities, an extensive shore-based infrastructure will be required to support, maintain, and operate such facilities. Maintenance and service costs will be directly proportional to proximity to shore. Such factors may have a strong influence on the desirability and siting of wave and current devices on the OCS. The impact of these relevant points on developing regulatory controls is not yet clear.

Potential is high for ocean energy technologies, but substantial challenges to commercialization remain, including the harsh offshore environment and the availability of on-site, in-water test data.

3.2 OCS Regulations

Regulatory processes are being developed in concert with the design, testing, and evaluation of wave and current energy conversion technologies. At this time the MMS has completed three significant milestones in the development of procedures for regulating renewable energy on the OCS[3] while also creating an environment that supports this emerging industry:

- A Programmatic Environmental Impact Statement, which examines potential environmental impacts and identifies policies and best management practices for the application of renewable energy technologies.

[2] Meeting with Derek Robinson of Wavebob, August 24, 2008, Annapolis, Maryland.
[3] According to the MMS, the Outer Continental Shelf encompasses “the submerged lands, subsoil and seabed lying between the states’ seaward jurisdiction and the seaward extent of federal jurisdiction,” some 1.76 billion acres.

- Interim policy, notably establishing an interim leasing policy that authorizes alternative energy resource assessment and technology testing activities on the OCS.
- Proposed Rule (30 CFR Parts 250, 285, and 290), in which regulations are proposed to establish a program to grant leases, easements, and rights-of-way; and establishing methods for revenue sharing for alternative energy program activities.

MMS has requested and received considerable public comment.

Given MMS's long and successful regulation of the OCS oil and gas program, many observers familiar with the program suggested that it be used as a model for developing alternative energy policies. While differences clearly exist between the oil and gas infrastructure and the infrastructure that will be needed for wave and current energy conversion, elements of the regulations common to both industries can be applied.

Chapter 4. Project Description

4.1 Objectives

The Minerals Management Service (MMS) seeks to advance the development of the alternative energy regulatory process pertaining specifically to wave- and current-energy conversion on the Outer Continental Shelf (OCS). MMS contracted with Free Flow Energy, an engineering consulting firm focused exclusively on new technology hydrokinetics, to assess the design and inspection criteria and standards for wave and current energy-generating devices.

We established a number of objectives for this project:

- Review the current technologies for wave and current energy conversion devices, offshore electrical transmission and interface, offshore facilities, anchoring and mooring systems, and offshore facilities management.
- Review engineering standards relevant to the design, development, implementation, test, operation, and decommissioning of wave and current energy conversion devices on the OCS.
- Review existing inspection and monitoring approaches and technologies for wave and current energy conversion devices, offshore electrical transmission and interface, offshore facilities, anchoring and mooring systems, and offshore facilities management
- Given current engineering standards for wave and current energy conversion devices, offshore electrical transmission and interface, offshore facilities, anchoring and mooring systems, and offshore facilities management, describe safety and regulatory concerns.
- Perform a gap analysis to determine the modifications to engineering specifications and regulatory standards needed to enable the implementation of wave and current energy conversion equipment on the U.S. OCS without compromising safety or performance.
- Recommend research initiatives to enhance the safe and effective regulation of wave and current energy conversion equipment devices, offshore electrical transmission and interface, offshore installations, anchoring and mooring, and offshore facilities management.
- Provide comments to the MMS Potential Incident of NonCompliance (PINC) list reflecting the results of our research and evaluation.

The focus of our research has been on wave and current energy conversion equipment and their supporting systems, not on site assessment and development of wave and/or current energy resource.

4.2 Methodology

Free Flow Energy's research and evaluation included acquiring basic engineering information, identifying candidate engineering standards, assessing inspection and monitoring protocols and technologies, and specifying safety and regulatory concerns. We employed literature searches of hardcopy, electronic media, and web-based sources (including MMS documents), plus in-person, telephone, and email interviews. Consultations included manufacturers of wave and current energy conversion devices, site developers, regulators, academics, investors, support industry, and other stakeholders. In-person consultations occurred at developers' facilities, university research laboratories, and conferences.

As part of our basic engineering information research, we also reviewed patents of ocean energy conversion devices to better understand the development of this equipment. This information not only provides a baseline for comparison, it also allows us to validate industry claims.

Free Flow Energy also created a meaningful categorization of engineering standards related to the implementation of wave and current energy conversion devices (see chapter 5). In doing so, we identified standards applicable to the implementation of wave and current devices on the OCS, including those that exist from oil and gas, unique to wave and/or current technologies, and standards under development.

Free Flow Energy supplemented its research via a questionnaire electronically transmitted to selected wave and current energy conversion device manufacturers.

Chapter 5. Engineering Standards

5.1 Engineering Standards Background

The Mineral Management Service (MMS) referenced a number of standards organizations in the proposed rule for energy conversion devices on the Outer Continental Shelf (OCS), "Alternative Energy and Alternative uses of Existing Facilities on the Outer Continental Shelf" (MMS 2008):

> "We [MMS] are in the process of reviewing international standards and guidance documents for Alternative Energy systems including those developed by the British Wind Energy Association, Det Norske Veritas, Germanischer Lloyds, IEC, and Energistyrelsen (Denmark). We are also assessing the applicability of certain American Petroleum Institute (API) and International Standards Organization (ISO) standards for offshore alternative energy structures, operating systems, and management practices. . . . The application of domestic and international standards will depend on the type of project, and regional and site-specific environmental conditions. The MMS may elect to incorporate into the regulations those standards that are expected to have widespread applicability to Alternative Energy projects. Other standards may be proposed by operators (or determined to be necessary by MMS) on a case-by-case basis."

MMS also noted in the proposed rule:

> "We selected the API RP 2A–WSD because there is a lack of standards for offshore alternative energy facilities and this standard has proven to be an effective assessment tool for other OCS structures in U.S. waters. The MMS would like comments on the use of this document for assessments and suggestions for other standards MMS should consider. This relates to the structure only and does not include production or transmission equipment . . . This proposed rule would require that operators report certain significant incidents associated with activities regulated under this part immediately . . . "

The development of regulations can involve a process similar to the one shown in exhibit 5-1.

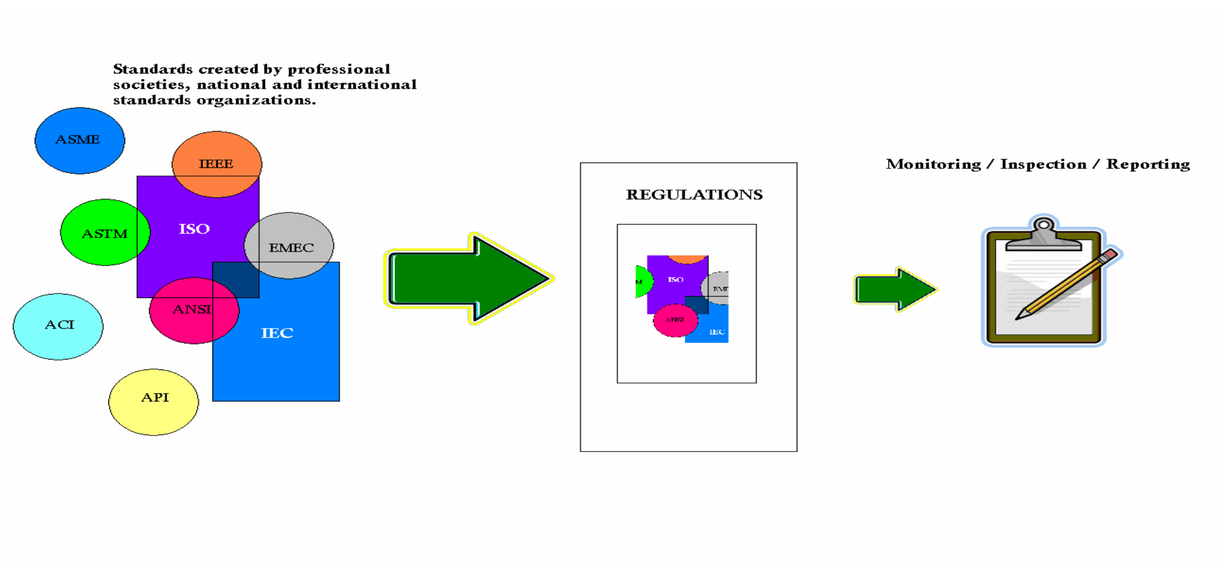

Exhibit 5-1. Flow of standards through regulations to monitoring, inspection, and reporting.[4]

[4] Free Flow Energy, 2009.

Several challenges become immediately apparent in the identification and review of candidate regulatory standards. Most notable is the existence of a high number of standards developing organizations, which in total produce thousands of standards. In addition:

- Significant duplication exists between standards developed by different organizations.
- Standards are not always easily accessible and can be prohibitively expensive.
- Knowledge about standards by some industry participants is limited.[5]

Several other important factors impact (and confound) the selection of standards relevant to wave and current energy conversion systems:

- Wave and current energy conversion equipment can vary dramatically.
- Power trains and transmissions technologies can vary significantly.
- Hardware for wave and current energy extraction can be installed throughout the water column, albeit with very different structures and mooring configurations.
- Energy storage or accumulation devices might be integrated into the energy conversion systems.
- No established system of standards or clear regulations exist for complex subsea power management.
- Hybrid systems covering multiple industries (e.g., hydrogen production and storage) are a possibility.

Some standards currently in effect under MMS jurisdiction can be applied to wave and current energy conversion systems, however these standards apply to structures as opposed to the energy conversion components themselves. The salient issue is the way in which these specifications will be applied. For example, oil drilling platforms are designed to accept waves in manners that will *reduce* loading within the carrying capacity of the structure. From a different perspective, wave- and current-driven devices need to be designed to *absorb* and *harness* this source of energy, while being properly and effectively anchored or moored within the environment.

International standards organizations such as the International Organization for Standardization[6] (ISO) and the International Electrotechnical Commission (IEC) attempt to harmonize the standards-development process by adopting, agreeing upon, and evolving national standards into international standards. In some cases, particular standards are well accepted and are adopted directly as international standards or joint standards, subject to agreements relating to copyrights, such as ISO/IEEE (Institute of Electrical and Electronics Engineers) and ISO/ASTM (American Society for Testing and Materials).

5.2 Engineering Standards Organizations

A number of organizations are addressing engineering standards for wave and current energy conversion systems, including:

- IEC
- ISO

[5] Few of the recipients of Free Flow Energy's device questionnaire were familiar with the applicable standards and regulations.
[6] Sometimes referred to as the "International Standards Organization."

- European Marine Energy Centre (EMEC)
- Ocean Energy Systems (OES) of the International Energy Agency (IEA)
- Insurance underwriters, such as Det Norske Veritas (DNV)

In addition to standards activities related to offshore oil and gas, the newly formed IEC Technical Committee 114 (TC 114), is specifically responsible for the development of standards pertinent to marine energy – specifically wave, tidal, and current energy conversion. (The United States has representation on that committee.) Standards presently under development were addressed as part of this research effort, however, the committee was recently formed and had its inaugural meeting in May 2008. Currently, the TC-114 is starting the review process for two new standards – one addressing the performance assessment of tidal energy converters, the other for wave resource assessment. If these draft standards are successfully developed, they likely will be finalized by the end of 2010.

Insurance underwriters will play an important role in the successful implementation of these technologies. Accordingly, insurance underwriters are now developing guidelines for wave and current energy conversion devices as well as driving the need for "certification programs" for marine energy. Insurers and certification organizations are looking very closely at the strength, reliability, safety, and value of proposed installations, and they are creating a significant body of work relevant to this effort and pertinent to the classification of subsystems. In addition to the development of these new standards, these underwriting organizations are drawing from their long involvement with the design, construction, operation, and maintenance of offshore structures used in related industries.

Other organizations involved in engineering standards development that potentially apply to wave and current energy conversion devices include:

- American Concrete Institute
- American Institute of Steel Construction
- American Petroleum Institute
- American Society of Mechanical Engineers
- American Welding Society

5.3 Engineering Standards Categorization

5.3.1 Approaches to Engineering Standards Categorization

One of the most important challenges underlying this gap analysis project was the need to categorize wave and current energy conversion systems into meaningful and understandable subsystems – essentially developing a categorization for the emerging technologies so the subsystems and standards applicable to each could be organized effectively.

A number of noteworthy attempts have been made in the past to organize or characterize technologies. For example, in a wave-energy report, the Electric Power Research Institute (EPRI) identifies *wave* devices with the following descriptors (Previsic, Bedard, and Hagerman 2004):

- Structural elements
- Power takeoff
- Mooring
- Survivability/failure Modes
- Grid integration

- Performance/tuneability
- Operation and maintenance
- Deployment and recovery

Likewise, in a key ocean energy report, EPRI characterizes *current* devices with the following descriptors (Bedard et al. 2005):

- Type: (Vertical axis, Horizontal Axis, Helical, Ducted, Twin, Open Center, etc.)
- Power Train Type: (Direct Drive, Hydraulic, Planetary Gearbox, Speed increaser, etc.)
- Foundation: Suspension, attached to sea floor, gravity base, monopole, anchors & chains)
- Rotor Size: Single or Double rotor with specified Diameter(s)
- Rated Power (kW): Typically 7 – 2000 kW
- Rated Speed: 2.1 – 3 meters/sec
- Area (m^2): 2.5 – 5092 m^2

The challenge of dividing hardware devices into meaningful subsystems was complicated because some hardware even transcends characterization as wave or current devices. For example patent 6,756,695 – designed, built, and tested by AeroVironments – uses wave action to move a float back and forth laterally from which the resulting currents rotate turbine blades, as show in exhibit 5-2.

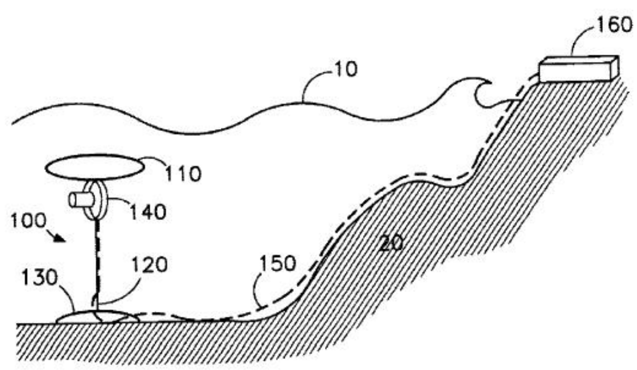

Exhibit 5-2. AeroVironments' design uses wave action to move a float laterally to rotate turbine blades.[7]

The EMEC "Draft Standard on Basis of Design of Marine Energy Converters" offers that marine renewable energy devices will have two main parts, as presented in exhibit 5-3.

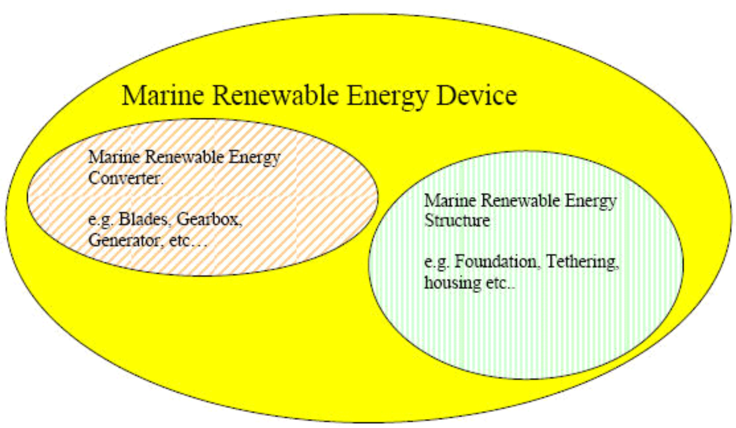

Exhibit 5-3. EMEC perspective of marine renewable energy devices.

[7] U.S. patent 6,756,695 B2, June, 29, 2004. Assignee: Aerovironments Inc.

ISO standards for use in the oil and gas industry are sometimes grouped as shown in exhibit 5-4 (which approximately resembles energy conversion subsystems).

General	Pipeline Transportation Systems	Fluids	Drilling & Production Equipment	Subsea Production Systems
Casing, tubing & drill pipes for wells	Offshore platform safety systems	Rotating equipment	Static equipment	Offshore structures

Exhibit 5-4. ISO Standards applicable to offshore oil and gas.[8]

The ISO standards organization appears in Exhibit 5-5.

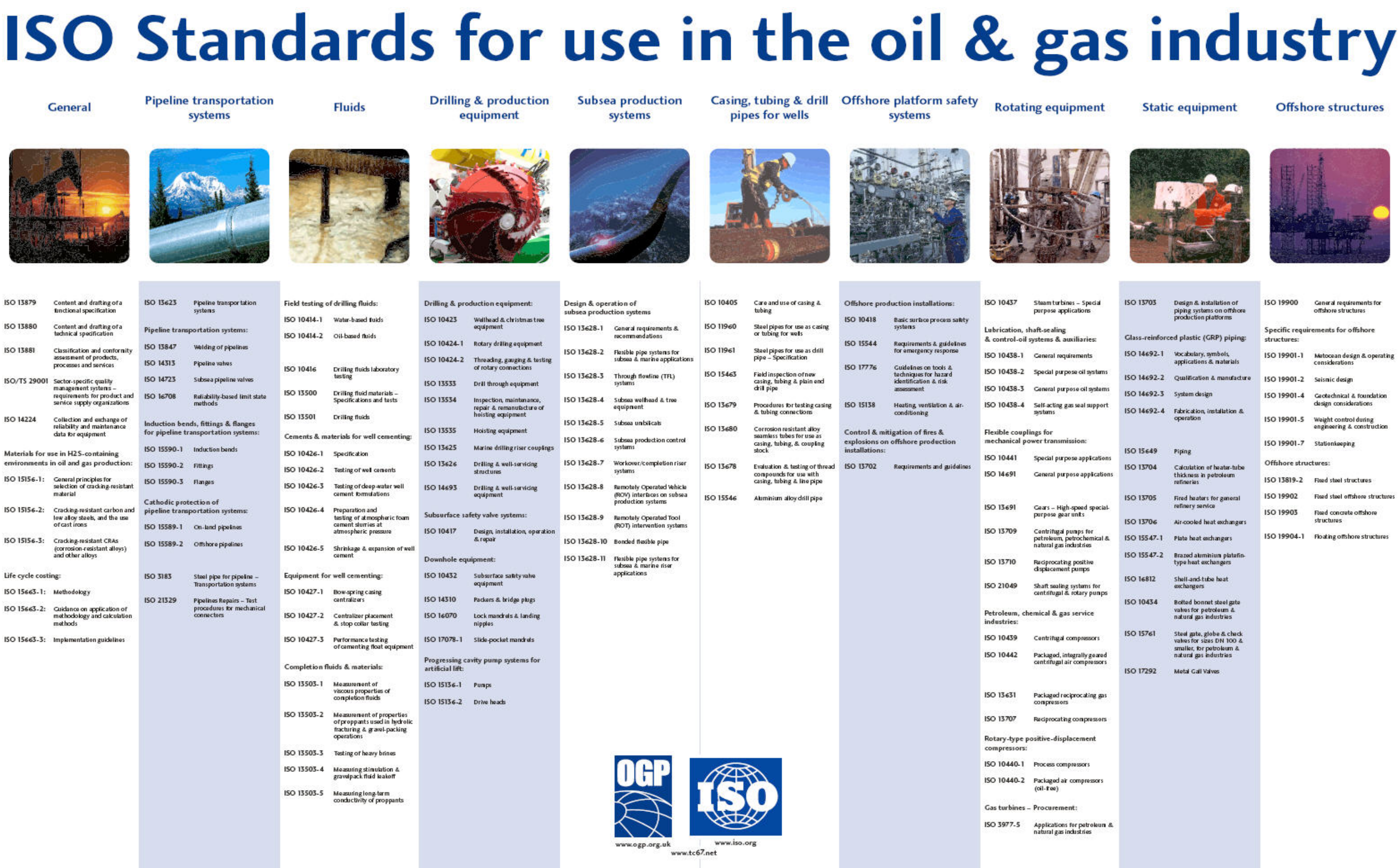

Exhibit 5-5. Organization of ISO standards for the oil and gas industry.[9]

[8] Free Flow Energy, 2009.
[9] Association of Oil and Gas Producers and International Organization for Standardization. http://isotc.iso.org/livelink/livelink/fetch/2000/2122/639895/639896/4612559/WPC2-StandardsColumnsPosters2005.pdf?nodeid=4613433&vernum=0.

5.3.2 Free Flow Energy Engineering Standards Categorization

It became obvious to Free Flow Energy that the first decision with regard to standards organization was whether to characterize wave and current energy conversion devices independently. Due to the high degree of overlapping subsystems between wave and current energy conversion devices – such as anchors and moorings, power transmission, power train, and even concept – Free Flow Energy decided to combine wave and current devices into a single classification system.

Another factor to consider in the selection of a suitable categorization was the phase of development. Wave and current systems and technologies require in-lab testing, in-situ demonstration testing, and proper site assessment and evaluation before construction, operation, monitoring, and inspection are even relevant. Standards and uniform practices are only now being developed pertinent to these pre-build out activities. Also, post-operation activities will exist for which still further regulations and standards will be developed – specifically the decommissioning or removal of hardware. Consequently, a timeline for wave and current energy conversion technologies might include design, in-laboratory testing, technology demonstration, site assessment and evaluation, construction and installation, monitoring and inspection, and decommissioning.

Due to the nascent and dynamic nature of technologies, any classification proposed will be subject to debate, however Free Flow Energy recommends applying a categorization similar to the classification system that has evolved for offshore oil and gas – specifically the use of ISO technical sub-committees to drive the selection of appropriate subsystems, discussed below. For example, as subcommittees form under TC 114, they likely add structure to the classification of subsystems.

For ease of access and application, Free Flow Energy has organized standards relevant for wave and current energy conversion systems on the OCS by project activity/function, as shown in exhibit 5.6. (See appendix A.)

Pre-construction			**Construction & Operation**						**Post-Construction**
Design, test & evaluation	Siting & environmental assessment	Classification, certification & insurance	Safety	Operation, maintenance, inspection & monitoring	Anchoring, moorings & foundations	Electric power, transmission & grid interconnect	General and/or statutory regulations	Offshore structures	Decom-missioning

Exhibit 5-6. Organization of standards and reports relevant to offshore wave and current energy conversion.[10]

[10] Free Flow Energy, 2009.

PART III – RESEARCH AND EVALUATION

Chapter 6. Engineering: Wave and Current Energy Conversion Devices

This chapter reviews the status of marine energy conversion hardware and addresses general engineering concerns that may impact inspection, monitoring, safety and survivability. Research was based on a thorough review of device manufacturers (as identified by the European Marine Energy Centre, the U.S. Department of Energy, the Wave Energy Centre, and other sources), as well as a review of engineering information relevant to energy storage, transmission, and in-situ operation.

6.1 State of Wave and Current Energy Conversion Device Technology

6.1.1 Wave and Current Energy Conversion Device Overview

The Outer Continental Shelf (OCS) environment creates some design *opportunities* – current flows are unidirectional, unlike tidal flows – and many design *challenges*. Offshore storms, for instance, and the salinity of ocean water (when compared with fresh water energy conversion) can confound OCS energy conversion systems design, implementation, and maintenance. In general, equipment designed for shallow fresh water risks failure when deployed in deep salt water because of corrosion related to salt and the higher pressures of deeper water. Some of the severe environmental factors can be ameliorated, however, if equipment is underwater, so engineers often will try to keep equipment entirely submerged so it doesn't experience harsh air-sea interface conditions.

According to leading experts, offshore wave and current energy conversion devices are likely to be relatively small in physical size and implemented in large arrays to facilitate maintenance, removal, and replacement in the demanding ocean environment.[11] This approach to wave and current energy system implementation will drive the need for elaborate control systems to facilitate electric power conditioning and integration.

Although a large number of candidate technologies are being evaluated or developed, ultimately only a small number of technologies are likely to succeed. Critical to the success of candidate technologies are "profitability, manufacturability, transportability, installability, survivability, operability, maintainability, and removability."[12] The most important of these is survivability in the relentless ocean environment. In fact, survivability of hardware should be of utmost concern to potential investors in wave and current technologies.

Various categories of wave and current energy conversion devices appear in exhibit 6-1.[13]

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[11] From discussions with British hydrokinetic energy experts who attended the Marine Renewable Energy Collaborative (MREC) conference, October 6, 2008.

[12] Dr. Robin Wallace of the University of Edinburgh recently summarized, quite appropriately, the prospects of the industry: "There are many different designs under consideration. As in other industries, several leaders will emerge. The requirements for success all end in '-ability.' They include: profitability, manufacturability, transportability, installability, survivability, operability, maintainability, and removability."

[13] For descriptions of these devices, visit the websites of the European Marine Energy Center (http://www.emec.org.uk/index.asp) and the U.S. Department of Energy Marine and Hydrokinetic Technology Database (http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx).

Wave	Current
Attenuator Pitching / Surging / Heaving / Sway Devices (PSHS) Oscillating Wave Surge Converter (OWSC) Oscillating Water Column (OWC) Overtopping Device Point Absorber Submerged Pressure Differential Other	Horizontal Axis Turbine Vertical Axis Turbine Oscillating Hydrofoil Venturi Effect Other

Exhibit 6-1. Categories of wave and current energy conversion devices.[14]

Through talking with device and site developers, visiting the websites of organizations involved with wave and current energy conversion, and reviewing the literature, a number of overarching summary observations about wave and current energy conversion devices emerged:

- A significant difference exists between proposing and implementing wave or current energy conversion.
- Many enabling technologies are in various stages of nascency and appear simply as drawings, computer animations, and scale models, making it difficult to determine or validate the technical or fiscal efficacy of much of the hardware.
- An enormous diversity of designs exists, but most are prototypes, at best, and few share common features.
- Many wave and current energy conversion device designs do not appear to have much chance of ever seeing widespread implementation (many are strictly on-shore devices).
- Many claims for energy conversion devices and/or sites cannot be verified.
- Few devices are being designed for converting wave or current energy offshore (such as on the OCS). The leading U.S. offshore investigator remains the Florida Atlantic University Center for Excellence in Ocean Energy Research.
- The technical resources, financial resources, and expertise of manufacturers and developers are largely unverifiable.
- A surprisingly large body of clever and potentially feasible designs dates to the mid 1800s.

Because wave and current energy conversion – notably on the OCS – is unproven, and because so many designs have been proposed (yet untested), it is not possible to "pick the winners." Due to the diffuse and intermittent nature of renewable energy (including ocean energy), *area* – that is, the area of the device impacted by waves and/or current – is critical. The more area, the more energy can be converted. However, device size must be limited to what is easily manufactured, transported, installed, and maintained. Consequently, large arrays of relatively smaller wave and/or current devices with elaborate control, monitoring, and inspection systems that are both survivable under extreme conditions, capable of being replaced on site, and cost effectively repaired or reconditioned on shore may have the best chance of success.

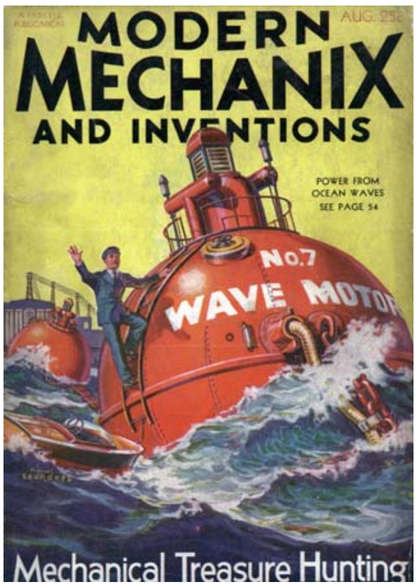
Beyond demonstration projects, it's most likely that production-model offshore energy devices will be applied first where the need is greatest – in-situ, where the power is generated – as with the early wind and solar energy conversion devices. Examples of offshore on-site energy production and use include offshore data acquisition (research buoys that already use wind and solar), ocean-based environmental monitoring, oil and gas platforms, maritime and military equipment, and remote locations (i.e., far from

[14] Free Flow Energy, 2009.

power grids). Some of the first production wave and current systems (non-demonstration) are already being applied in areas where power is extremely scarce and therefore more valuable, such as in developing countries.

6.1.2 Challenges of Classifying Hardware

Wave and current energy conversion devices in development today reflect a long history – over 160 years – as well as composite designs. As aptly illustrated in exhibit 6-2, harnessing wave and current energy is not a new idea.



Early devices designed to harness wave and current energy – typically called wave or current *motors* – often were designed for near-shore applications. These devices commonly were used to compress air or pump water. It wasn't until the early twentieth century that wave and current energy conversion devices were used to generate electricity. Early offshore wave devices were applied to in-situ applications such as the "bell buoy" and "whistling buoys," the precursors of oscillating-water-column devices, designed to make sounds to warn and guide mariners. (When reviewing the many hundreds of wave and current device patents issued over decades, it becomes immediately obvious that the *other* categories in exhibit 6-1 above are very large. Many of these patents are more detailed and meticulously written than anything found on the web today and reviewing them gives clear meaning to the term "prior art.")

Exhibit 6-2. *Modern Mechanix and Inventions* features wave energy conversion in a 1932 issue (MMI 1932).

Many ocean energy hardware designs employ various combinations of technology. An overtopping device such as the Wave Dragon, for example, uses water elevated by *waves* to fill a containment reservoir (overtopping), after which energy is extracted from the *currents* as the water moves from higher to lower potential energy.[15] The device shown in exhibit 5.2 from a recent patent by AeroVironment uses *wave* motion to cause an excessively buoyant float to move back and forth horizontally as a rotary turbine then converts the passing water into electricity. (AeroVironment was one of the most visible and highly publicized investigators of current energy conversion in the Gulf Stream to which the exhibit 6-3 September 1980 cover of *Popular Science* was devoted.) Designs also combine such features as hydraulic and pneumatic power transmission and energy storage as components of electrical power generation. Consequently, wave and current energy conversion devices do not permit the development of a simple, clean characterization or orderly nomenclature.

Exhibit 6-3. Nearly 30 years ago, *Popular Science* featured "undersea turbines" as a cover story (PS 1980).

15 http://www.wavedragon.net/

6.1.3 Hardware Subsystems

Certain components and subsystems are common to most water-energy conversion systems. Hardware subsystems common to most hydrokinetic energy conversion systems – or features that can be added or removed, depending upon the circumstances of the site – are discussed below. In all cases water (fluid) motion is the prime mover. (By prime mover we mean the initial mechanical agent that puts a machine in motion.) While one could argue that the water motion is caused by wind, density gradients, planetary motion, or the sun, we are more narrowly considering water motion as the prime mover of ocean energy conversion devices.

Some devices use ducting to accelerate flow and direct it into a turbine as well as ducting to reduce the pressure at the exit side of the turbine, which could be considered a subsystem.

6.1.3.1 Rotary and Reciprocating Devices

Fluid motion acts on mechanical devices and linkages to create rotary or reciprocating motion – such as spinning the blades of a turbine. Addressing the up and down motion of waves is not as simple as *pitch*, *surge*, *heave*, and *sway*. Also, the term *oscillatory* or *oscillating* – which implies sinusoidal motion (e.g., simple harmonic oscillation), can be misleading since waves and currents are certainly not necessarily "sinusoidal" and in fact, are far more chaotic, and need to be described by a spectrum of waves at different frequencies and amplitudes. We have opted for the term *reciprocating*, meaning simply moving back and forth, or up and down.

Regardless of whether the mechanical device operates in a rotary or reciprocating fashion, the output device leads to some sort of power takeoff.

6.1.3.2 Power Takeoff

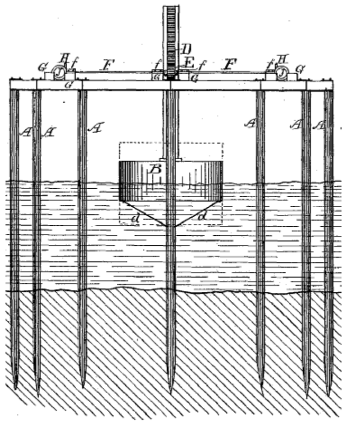
The power takeoff transfers power to another device, such as a pump, compressed-air storage, a hydraulic accumulator, or an electrical generator. For clarity, the term power takeoff is applied to the equipment put between the water-actuated device and the pump, generator, power transmission or energy storage devices.

Power takeoff can involve many components, including linkages, levers, gears and gearboxes, speed enhancers, clutches, safety disconnects, and brakes. Power takeoff plays a critical role in power conditioning, transmission safety, and survivability of hardware. Its primary function in ocean applications is to accelerate the relatively slow mechanical motions of currents and waves and to translate the motion to energy conversion and/or storage devices.

6.1.3.3 Energy Conversion Hardware

As previously mentioned, the very earliest wave and current *motors* typically compressed air, pumped water for storage, or pumped other fluids. A few free-flow designs, similar to early conventional hydropower waterwheels, used the power directly via systems of gears, belts, and pulleys to operate shore-based facilities. As noted, electrical generators and batteries were not applied until the early twentieth century. Since that time, the majority of designs have focused on electric power generation either by directly driving the (linear or rotary) generator or by using intermediate means of compressed air or hydraulic fluid.

Early wave and current devices were most often used to drive pistons that compressed air which was piped to shore, as shown in exhibit 6-4.



The choice of using water, air, hydraulic fluid, or electricity to transform hydrokinetic energy into something able to perform useful work depends on many different variables. A significant determinant is whether the energy will be consumed in situ, close to shore, stored, power conditioned on site, or transmitted over long distances.

Exhibit 6-4. A "Mechanism for Utilizing Wave-Power," patented in 1895, exemplifies serious early attempts to harness the power of the sea.[16]

6.1.3.4 Energy Storage

Energy storage, which performs numerous functions, can be performed by a variety of techniques, including power quality management and power conditioning, small-scale in-situ storage, back-up power, transmission and distribution, load management, and load leveling. Due to the intermittent nature of renewable energies, storage will play an important role (even for more-predicable sources like tidal current energy). When large quantities of ocean energy become available, it will be important to be able to sell the power at times that coincide with peak demand when the energy is most valuable. Until large quantities of energy are available from the ocean it is reasonable to assume that energy storage will be of greatest value in power conditioning.

Energy can be stored several different ways – batteries, compressed gas, flywheels, hydrogen, pumped hydro, and ultra- capacitors, each with its own advantages and disadvantages.

6.1.4 Impacts of Depth on Wave and Current Energy Conversion Devices

The position of an energy conversion device within the water column can be as important as geographical coordinates, yet depth often receives inordinately less attention. (For the purposes of this discussion, we have considered only the factors and impacts relevant to vertical placement at a given OCS site; impacts and factors due to latitude and longitude will not be considered, although they are relevant.)

The vertical position of wave and current energy conversion devices has numerous design, operational, and survivability ramifications, including:

- Impact on competitive uses (e.g., maritime and commercial fisheries)
- Environmental impact
- Impact of aquatic plants and marine life on design
- Impact of aquatic plants and marine life on survivability
- Installation, maintenance, repair, and decommissioning access and cost
- Sedimentation and bottom impacts on moorings and foundations
- Location of maximum energy conversion and efficiency

[16] U.S. patent 321,229, June 1865. Inventor: Charles Leavitt.

The physical make up of the ocean changes significantly with depth: hardware-crushing pressure increases, life-supporting light and oxygen decrease, corrosive salinity increases, and temperature decreases, as shown in exhibit 6-5. Another critical factor is sound (which travels at 1,450 meters per second in sea water, compared with 334 meters per second in air), which can have an impact on marine animals; sound speed increases as water temperature decreases (and therefore depth). In all of these respects, the positioning of devices within the water column is an important factor in the siting process.

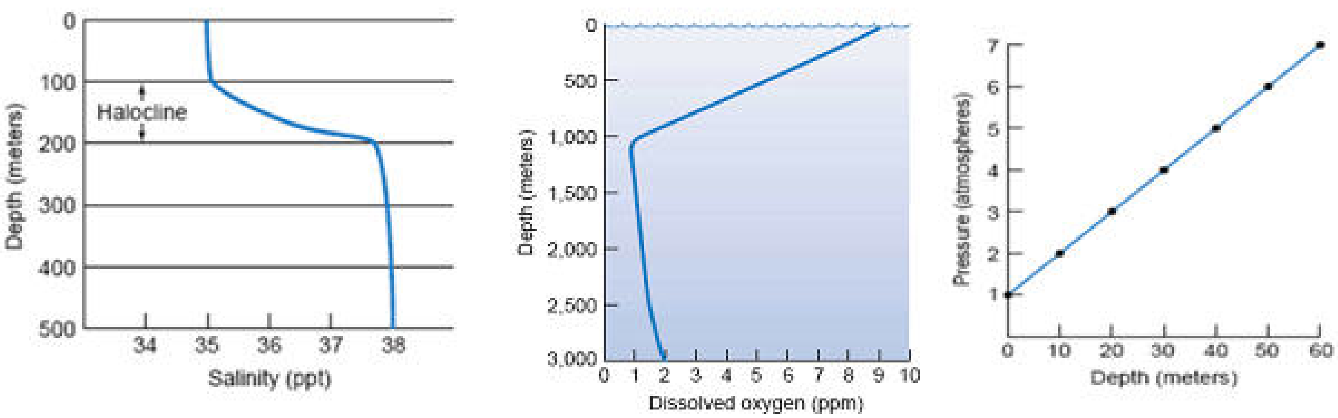


Exhibit 6-5. Variations of salinity, dissolved oxygen, and pressure with depth.[17]

The continental shelf, which varies considerably in width, is subdivided into the inner, mid, and outer continental shelves, each with its own geomorphology and marine biology. The depth of the shelf also varies considerably, but it is generally limited to water shallower than 150 meters (490 feet). The continental shelf is sloped, but the slope is quite low (less than one degree) so we have further bound the discussion by considering depths not greater than 150 meters.

For our research we assumed that wave and current energy conversion activity on the continental shelf will likely occur in the epipelagic or "sunlight" zone, as illustrated by exhibit 6-6.

[17] http://www.wicknet.org/science/gpratt/Physical%20and%20Chemical%20Factors.ppt

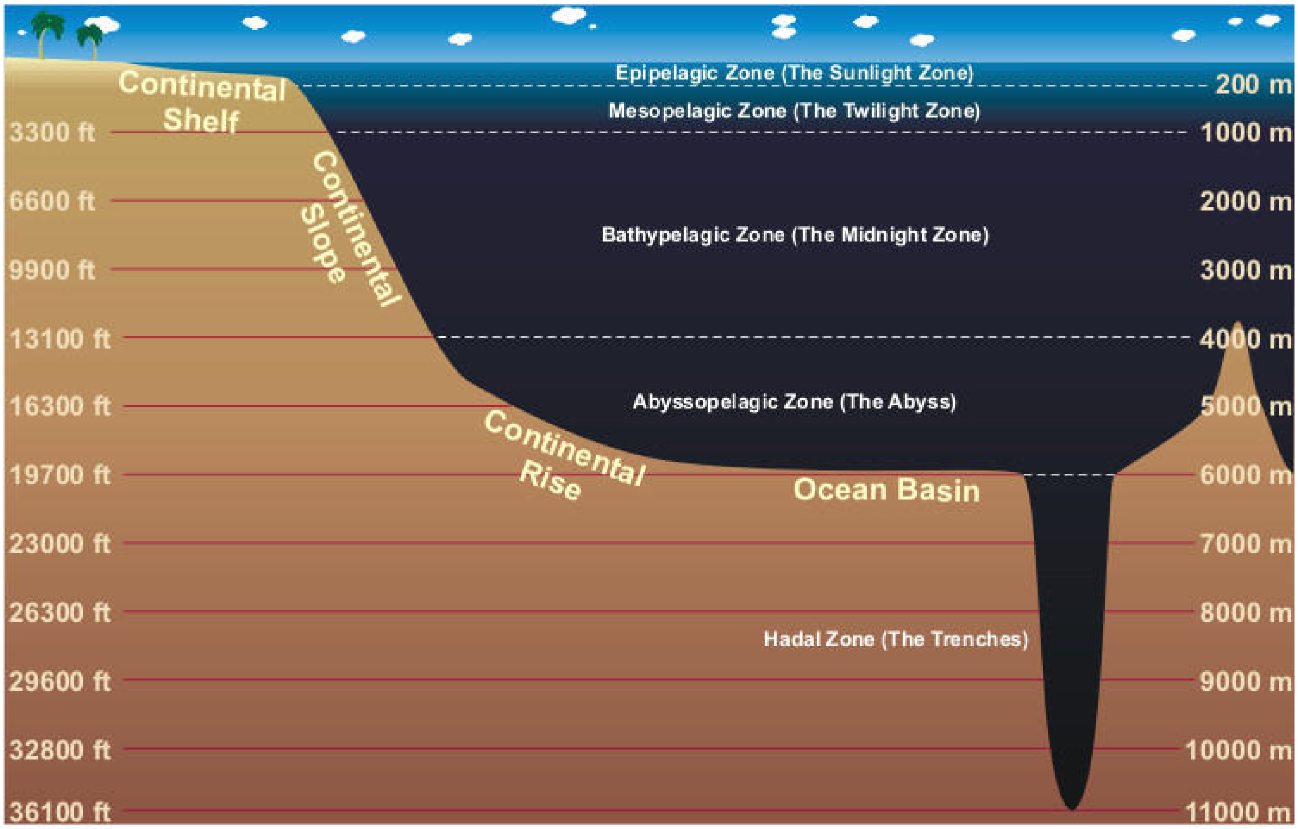


Exhibit 6-6. Profile of the ocean.[18]

Other factors impacting the placement of energy conversion with regard to depth include:

- Navigational considerations and depth
- Commercial fisheries
- Environmental impacts
- Design considerations
- Maintenance and serviceability
- Moorings and anchoring (depth and bottom morphology)
- Positioning for maximum energy conversion
- Survivability under extreme conditions
- Type of energy conversion device

6.1.4.1 Navigational Considerations and Depth

For this investigation, we can assume that all wave and current energy conversion devices will be fixed to the bottom in some manner. (Even "raft mounted" devices must be secured.) The significance of this lies in the potential impact on navigation and in providing adequate minimum under-keel clearance at the site. (Under keel clearance is addressed in 33 CFR 157.455.) So clearance may need to be provided at the top of energy conversion installations – not the bottom.

[18] National Oceanic and Atmospheric Administration.

6.1.4.2 Commercial Fisheries

The potential impact of hydrokinetics on commercial fisheries is critical. The primary issue relates to the historic self-regulation of many commercial fisheries. In many locales, fishermen negotiate fishing zones among themselves without federal intervention. Violating these self-established rules have met with self-established consequences. The coordinates of fishing areas are in many cases the property, livelihood, and legacy of fishermen – *proprietary information* (for lack of a better term) that has been handed down and respected for generations. The "numbers" and coordinates used by fishermen may not be maintained or even known by government regulators, who are otherwise assigning priority of application to resources. Depth, however, is less of a concern to fisherman than geographical coordinates as just about anything put in the water column will impact almost any fishery: dragging, gill netting, long lining, purse seining, lobstering, crabbing, etc.

Some studies, such as the Coastal Ocean Dynamics Experiment (CODE) on the Northern California coast and the TOGA/TAO Moored array along the equator, have documented that fish may accumulate around the moorings and that fishermen will take advantage of the attractiveness of moorings to increase fish catches. Collaboration was established during the CODE experiment when fishermen notified the scientists about problems with the moorings: The fishermen didn't want the moorings removed when the experiment was completed!

6.1.4.3 Environmental Impacts

Most marine and aquatic plants and animals live in the epipelagic zone – from the surface to 200 meters. Since most energy conversion devices are likely to be positioned within 200 meters of the surface, hardware and marine species will have to coexist in the same space at the same depths.

Regulators, environmental organizations and developers will have to work together closely to address entanglement (see exhibit 6-7), noise, impacts and other potential problems. Because there are so many unknowns related to wave and current energy conversion, inspection and monitoring will be most critical in to this aspect of marine hydrokinetics.

Exhibit 6-7. Marine entanglement threatens some marine species.[19]

6.1.4.4 Design Considerations

From the perspective of depth, the key design issues are likely be high pressure, the corrosive effects of salinity, and growth of marine plants and crustaceans on devices positioned in the photic region. (See exhibit 6-8.) While shaft seals are capable of preventing water from entering enclosures, they introduce friction with a resulting decrease in speed and overall system efficiency. Flooded-cavity designs can provide back pressure and can somewhat counteract the effects of submersion, but they also compromise efficiency and overall system performance.

[19] http://wildwhales.org/wp-content/themes/wildwhales/images/entanglement1popup.jpg

The corrosive effects of salinity and the impact of marine growth can be addressed through a combination of various surface coatings and cathodic-protection systems. Nevertheless, mechanical cleaning often must be employed since many anti-fouling coatings are very poisonous and if used in large quantities can cause significant environmental damage, a major problem. Also, biofouling effects differ widely with the environment and location (e.g., East Coast, West Coast, Gulf Coast).

Exhibit 6-8. Growth of marine organisms will be a maintenance challenge.[20]

6.1.4.5 Maintenance and Serviceability

Two important considerations with regard to depth of hardware are maintenance and serviceability. SCUBA or non-decompression dives should not exceed 130 feet (40 meters). Although underwater submersible vehicles and hardware can go to far greater depths, it comes at a price. It is reasonable to assert that installation and maintenance costs of energy conversion devices will increase with depth.

6.1.4.6 Moorings and Anchoring Depth Considerations

Moorings and anchors (see chapter 9) and foundations, too, will be impacted by depth. Wave devices positioned on the surface with minimal draft (most of the device above the surface) would by definition require less anchoring and smaller footprints than pressure differential wave devices and current turbines in which the entire device must be held submerged at a depth optimized for energy conversion efficiency.

6.1.4.7 Positioning for Maximum Energy Conversion

It is quite possible that current devices will be limited to unique sites, such as the Gulf Stream or perhaps deep water currents such as those found in the unique marine topography of the Gulf of Mexico.

While it is not clear yet whether surface point absorber or pressure differential wave energy devices are more productive or efficient, cost and maintainability are likely to favor surface devices, while submerged devices offer the advantage of not obstructing navigation or being visible to the public.

6.1.4.8 Survivability Under Extreme Conditions

Without question devices installed at depth benefit from not being exposed to high winds and violent ocean surface waves. On the other hand, storm surge, internal solitary waves, current shear, and the difficulty of anchoring submerged devices pose other problems of survivability in extreme events.

[20] http://www.woodbridge.tased.edu.au/MDC/Species%20Register/Barnacle-Tetra.jpg

6.1.4.9 Impacts of Depth on Various Types of Energy Conversion Devices

6.1.4.9.1 Surface Devices

Point absorbers, attenuators, overtopping devices, and oscillating-water-column devices are wave energy converters likely to be found moored close to or on the surface, with anchors extending to the bottom. (See exhibit 6-9.) Alternately, some devices under consideration put the float at the surface and the generator on the bottom – with reciprocating motion translated via column or cable through the water column.

Current devices typically are not found at the surface, however, control and operator stations may be located at the surface as in the case of the Marine Current Turbines SeaGen device.

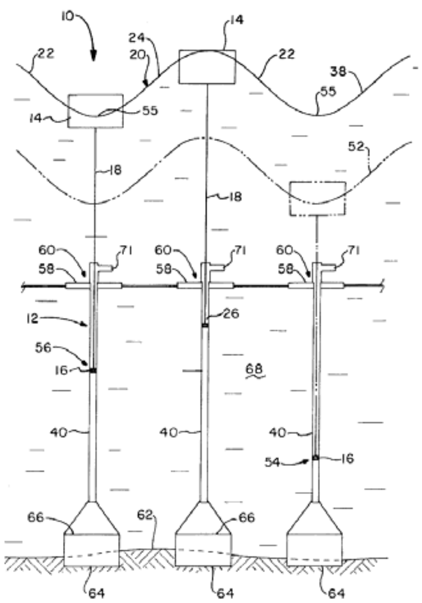


Exhibit 6-9. Surface energy conversion devices.[21]

6.1.4.9.2 Mid-Water-Column Devices

Most current devices are designed for operation below the surface but not necessarily at the bottom. (See exhibit 6-10.) Horizontal- and vertical-axis turbines can be permanently fixed to the bottom or float freely in mid water currents. Wave devices such as submerged pressure differential devices may be found at various depths in the water column.

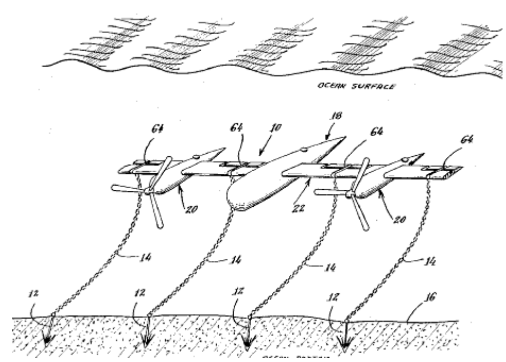


Exhibit 6-10. Mid-water-column energy conversion devices.[22]

[21] Hydro Electric Plant, U.S. patent: 6,388,342 B1, May 14, 2002. Inventor: Richard Vetterick Sr. and Jr..
[22] Underwater Power Generator, U.S. patent: 4,383,182, May 10, 1983. Inventor: Wallace Bowley.

6.1.4.9.3 Bottom-Mount Devices

Devices that are difficult to stabilize via anchoring or are so buoyant that they become an extreme challenge to hold submerged are apt to be bottom mounted. (See exhibit 6-11.) These include "pitching, surging, heaving, swaying" (PSHS) devices, Archimedes Wave Swing and larger devices, such as venturi designs, and larger, gravity-based,, horizontal- and vertical-axis turbines.

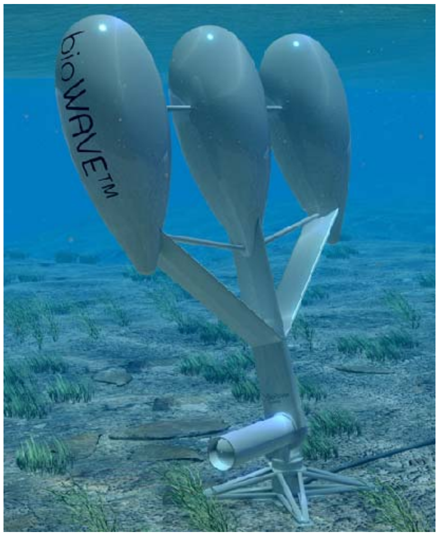


Exhibit 6-11. Bottom-mount energy conversion devices.[23]

6.2 Wave and Current Energy Conversion Device Inspection and Monitoring

MMS provides scheduled and unscheduled inspections of facilities and enforces federal regulations as authorized by the OCS Lands Act and the Energy Policy Act of 2005. Inspections by the MMS utilize a checklist called the Potential Incident of NonCompliance (PINC) list. It is assumed that this research effort and others will lead to the selection of existing or the creation of new PINCs suitable to the application of wave and current energy conversion.

MMS provides guidance with regard to pollution monitoring and inspections for offshore oil and gas production facilities. Since the pollution and environmental impacts of offshore wave and current energy conversion have not yet been defined, equivalent guidance and directives do not yet appear to be available.[24]

A robust inspection and monitoring system for wave and current energy conversion devices benefits everyone: owners, regulators, abutters, utilities, and the public – and even groups sharing the same resource, such as maritime and commercial fisheries. Unlike the past when "failure" analysis was used to reveal the shortcomings of design, today modeling, sensors, software, and telecommunications enable live data acquisition and analysis of virtually any aspect of a complex system. Streaming data and an accumulating history facilitates real-time control, which can optimize performance, prevent failures, and ensures safety, often before problems occur. Applications of state-of-the-art inspection and monitoring are particularly relevant to new technologies and demonstration projects.

While inspection and monitoring may initially seem to be a necessary and costly evil imposed by regulators to confirm the compliance and safety of devices, owners and operators are likely to be the greatest beneficiaries of well-engineered monitoring systems. Modern data acquisition and analysis can optimize the performance (and profitability) of systems, minimize risk, ensure safety, extend the lifetime of hardware, and predict the need for servicing of offshore devices – justification for the expense, time, and effort required to implement inspection and monitoring systems.

[23] BioPower Systems: http://www.biopowersystems.com/technologies.php
[24] See Notice to Lessees and Operators: NTL No. 2008-G03.

For regulators, proper and timely inspection and monitoring regimes are necessary to ensure safety, minimize environmental and operational risks, and to confirm that owners are using public resources in the best interest of the public.

Information made available to the public from ocean energy installations will almost certainly be of value to mariners, commercial fisheries, and the public, as is data from National Oceanic and Atmospheric Administration (NOAA) and National Data Buoy Center (NDBC) buoys and U.S. Geological Survey gauging stations, environmental . Cape Wind, for example, now streams real-time weather and sea conditions to the public from the environmental monitoring station located in Nantucket Sound.

6.2.1 Offshore Inspection and Monitoring Industry

A large and well established industry currently exists to facilitate offshore inspection and monitoring of ocean renewable energy. A lot has changed, however, since a 1978 paper by Busby Associates gave the diver as the primary inspector, with "visual inspection, photographic and TV documentation as his primary tools," in addition to bringing cleaning devices – such as a wire brush and chipping hammer – to the inspection site (Busby 1978). Surveys at that time consisted primarily of visual inspection for the following (all of which are relevant today):

- Broken or bent members
- Corrosion
- Corrosion system effectiveness
- Cracking and Pitting
- Debris Accumulation
- Scouring at platform base

Manned and remotely controlled vehicles, as well as the application of analog electronics (such as ultrasonic inspection and radiography) were introduced in the 1970s. Today, sensor, computer and telecommunications technologies are now well developed and widely applied, with a range of inspection and monitoring hardware, software, and services companies clearly capable and ready for and welcoming the opportunities presented by offshore renewable energy.

The *structure* is, of course, the primary candidate for the application of monitoring and inspection systems. Offshore structures are divided into three distinct areas, each with its own unique conditions and requirements:

- *Topside* – hardware not generally exposed to salt water but regularly subjected to the effects of wind and sun, plus salt spray.

- *Splash zone* – the area of the structure between the wave crest levels of highest astronomical tides (HAT) to slightly below the extreme of lowest astronomical tides (LAT). It is the region where the extreme forces of wind and waves and the effects and constant wetting and drying cycles act on structure.

- *Subsea* – the area extending from the splash zone to the sea bed, including all parts of a structure constantly submerged – moorings, anchors and/or foundations. Energy conversion hardware exposed to subsea conditions can vary drastically depending upon the type, design and purpose of the device. Pressure and sedimentation are factors specific to subsea.

Environment is the second major focus of monitoring activities. Environmental monitoring consists of three primary subgroups – wind, waves, and currents – the primary sources of pressures, forces, and actions imparted to offshore structures. Exposure to solar radiation is also a consideration due to its ability to deteriorate materials and impart thermal cycling and temperature extremes. Environmental monitoring of marine sea life including fish, marine mammals, shellfish, benthic species , and possibly even birds is relevant, although this type of monitoring is quite site and technology specific. It is most foreseeable that a period of environmental monitoring will be required prior to and during construction, and then for some period of time during operation of devices.

Perhaps a third type of monitoring or subset of environmental monitoring may includes *human factors* and *human impacts*. This would include closer inspection and monitoring of navigational, maritime, commercial fisheries, military, telecommunications, recreational and human factors such as visible and audible conditions of sites.

6.2.2 General Types of Inspection and Monitoring

Inspection and monitoring activities can be categorized as environmental and structural, although some of these activities will impact both categories. Likely monitoring and inspection activities before, during, and after the construction of offshore wave and current energy conversion installations include:

Environmental –

- Anti-perching and nesting relevant to avian species and bats
- Aquatic vegetation and marine habitat
- Avian considerations (migration routes, perching, and nesting)
- Benthic organisms species and shellfish
- Electromagnetic fields
- Fish and marine mammals
- Historical and archaeological elements
- Monitoring the use of devices as artificial reefs for food, shelter, spawning and refuge by marine species.
- Navigation, transportation, and competing uses
- Potential impacts due to energy extraction
- Potential impacts on telecommunications
- Sedimentation and scouring
- Visual and noise impacts
- Water quality

Structural –

- General inspection: cracks, strain, stress, corrosion, cracking and pitting, movement of hardware, condition, operability, etc.
- Accumulation and impacts of marine debris
- Collision detection and avoidance systems
- Control system operability and functionality
- Detection, mitigation, resolution and reporting of entanglement
- Existence and condition of shore-based support infrastructure
- Existence and functionality of aids to navigation
- Existence, status, update, and revision of emergency response plans and equipment
- Marine growth and accumulation
- Moorings and anchors

- Oil spill detection, response and reporting
- Power transmission cable burial depth and condition
- Safety equipment condition, location and availability
- Shutdown and disable capabilities
- Survivability and inspection following extreme events

Structural inspection types include visual, for topside inspection; diver and remotely operated vehicle (ROV), for subsea inspection; plus other specialized inspections, such as nondestructive testing.

The construction phase by it's very nature has the potential for greatest risk because of vessel traffic to and from the site, cable installation, pile driving, the operation of marine construction equipment, the use of fuels and fluids by vessels and other equipment, seabed impacts for anchoring and foundations, and the high level of activity of men and machines. Again, however, this remains technology and site specific.

As a point of interest, European offshore wind farm developers conducted baseline monitoring for three years prior to construction. This length of monitoring gave developers information on the local conditions at the proposed site, giving them an estimate of the seasonal, interannual variability, and extreme conditions. With regard to wave and current energy conversion installations, this type of environment information is important input for the proper design of moorings and anchors, structures, and the energy conversion systems.

6.2.3 Available Inspection and Monitoring Technologies

The long history of offshore oil and natural gas mining has resulted in a significant monitoring and inspection infrastructure suitable for direct application to ocean-based renewable energy. A broad range of sophisticated monitoring and inspection sensors, data acquisition and analysis software, and telecommunications to facilitate in-situ and remote monitoring stand ready for implementation. (See exhibit 6-12.)

Marine-grade, submersible sensors, sensor suites, and systems are ready, tested and available for immediate application with few or no identifiable gaps. This is in sharp contrast to the 1978 report mentioned earlier in which inspections were largely dependent on the visual and photographic capabilities and limitations of divers. Modern inspection and monitoring systems measure the air above installations to conditions within the seabed using instrumentation ranging from nano-scale technologies to satellite based remote sensing systems – most fully automated and fully web enabled.

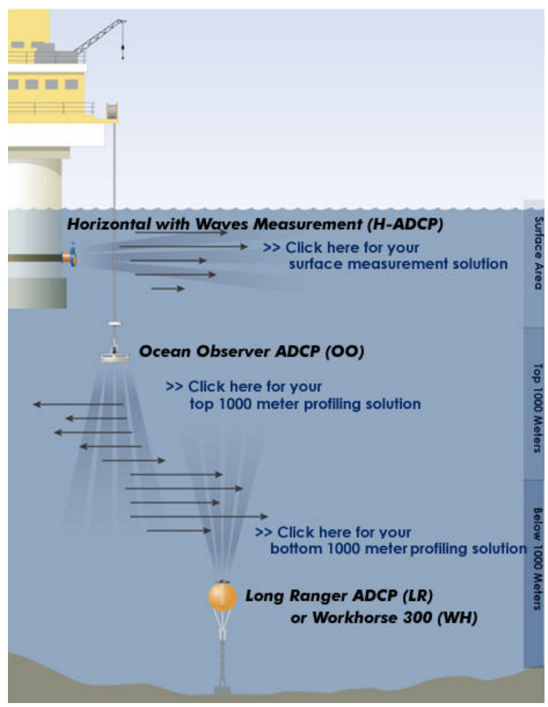


Exhibit 6-12. Common ADCP applications.[25]

[25] http://rdinstruments.com/observer.html

Loads applied to offshore hardware typically originate from environmental conditions, such as wave, wind and current. As such, environmental monitoring and structural monitoring are not mutually exclusive.

Some of the most likely technologies and methodologies to be applied in the inspection and monitoring of offshore current and wave technologies include (discussed below):

- Acoustic Doppler current profilers (ADCP)
- Accelerometers and gyros
- Cathodic protection and corrosion monitoring systems
- Didson sonar
- Eddy-current testing
- Geospatial detection
- Infrared inspection
- Mid-infrared evanescent wave sensors
- Physical inspection methods
- Physical oceanography sensor suites
- Remote and autonomous underwater vehicles
- Strain gauges and load cells and pressure gauges/transducers
- Ultrasonic guided wave technology
- Ultrasound
- Wave radar
- Weather monitoring

6.2.3.1 Acoustic Doppler Current Profilers

Acoustic Doppler current profilers (ADCP) monitor horizontal and vertical fluid dynamic conditions within the water column as a function of time. This allow the detection of large, intermittent strong internal solitary waves, subsurface effects of surface waves, and surface directional wave spectra, as well as ocean current structure. ADCPs can detect fish and other objects in the water at a distance from the sensor and provide profiles of suspended particulates.

6.2.3.2 Accelerometers and Gyros

The motion of floating devices is essentially characterized by six degrees of freedom – three for translation (surge, sway, and heave) and three for rotations (roll, pitch, and yaw). Translations are typically monitored with three-axis accelerometers and rotations via three solid-state gyros covering all six modes of motion. Accelerometers also can detect and measure vortex-induced vibrations (VIV) that have been problematic in other types of offshore structures and marine cables.

Three-axis magnetometers (fluxgate compasses) provide exact orientation and motion of the structure. These sensors are the same as used in buoys to measure the surface wave spectra by scientists, the National Data Buoy Center, and regional observatories.

6.2.3.3 Cathodic Protection and Corrosion Monitoring Systems

While cathodic protection systems help prevent corrosion-based damage to subsea structures, cathodic monitoring systems help ensure the robustness of cathodic systems and the devices they protect.

6.2.3.4 Didson Sonar

Didson sonar provides high-definition sonar imaging of structures and objects underwater for leak and flow detection, fisheries management, inspection, and search and recovery. Didson sonar uses both new acoustic lens technology and the fact that the ocean is more transparent to acoustic energy than to light. This technology can image underwater structures and moorings in a manner similar to a video camera in dynamic regions with low visibility due to suspended particulate matter.

6.2.3.5 Eddy-Current Testing

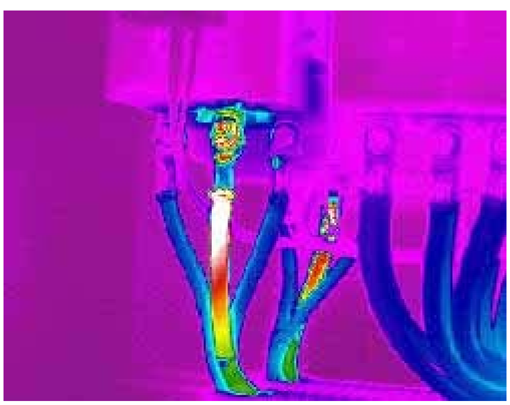
In eddy current testing, a circular coil carrying alternating current (AC) is placed in close proximity to metal being tested for material wear and defects. The changing magnetic field from the AC coil induces eddy currents in the metal under evaluation. Variations in the phase and magnitude of the induced eddy currents can be measured using a secondary search coil. The resulting measurements can be used to detect cracks, thickness degradation, and assess the condition of coatings. Eddy current testing is particularly sensitive and useful in the detection of small cracks and surface defects.

6.2.3.6 Geospatial Detection

Geospatial detection – global positioning systems (GPS), differential global positioning systems (DGPS), and geographic information systems (GIS) – and remote sensing and satellite telemetry have become mainstream. DGPS offers greater accuracy than GPS, while GIS acquire, analyze and report spatial information of the type typically found in two-dimensional and three-dimensional maps. A range of satellite-based monitoring systems for tracking movements and forecasting extreme events employ a range of sensor types and wavelengths. Due to costs associated with remote sensing, it is most likely that government organizations, such as the National Oceanic and Atmospheric Administration (NOAA), will drive the application of these technologies.

6.2.3.7 Infrared Inspections

Infrared test and measurement equipment is used to detect variations in temperature. Because infrared inspections can provide early detection of a temperature increase in electrical components – which commonly occurs before failure – this test technology can be useful in marine energy systems. Likewise, energized components that *should* be warm, but aren't, can be quickly identified as well.



Infrared can also be used in the detection of leaks, cracks and structural failure.

High-quality graphic images that are easy to interpret and web enable can be produced in infrared testing (see exhibit 6-13), a most useful aspect of the technology.

Exhibit 6-13. High-quality graphic image from an infrared inspection.

6.2.3.8 Mid-Infrared Evanescent Wave Sensors

Mid-infrared evanescent wave sensors operating in the spectral range of 3 -20 micrometers in seawater are useful for the in situ and real-time monitoring of hazardous pollutants in seawater and marine monitoring.

6.2.3.9 Physical Inspection Methods

Although electronic sensors and computer technologies automate much of the inspection process, the physical inspection and monitoring of devices and installations will be inevitable. Verification of safety and environmental hazard equipment, personnel and procedures, inspecting for marine growth debris accumulation and general assessments of structure are unavoidable.

6.2.3.10 Physical Oceanography Sensor Suites

The full range of classic physical oceanography sensors are relevant to the monitoring and inspection of wave and current energy conversion sites, including pressure, temperature, acoustic sensors, and ion electrode measurement systems (such as pH).

6.2.3.11 Remotely Operated Vehicles and Autonomous Underwater Vehicles

Remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) can provide a range of tests, especially visual inspections of structure, transmission cable, mooring, anchor and foundation inspections. (Didson sonars are one such option. See above.) They are most valuable in dangerous environments or where diving is not practicable.

6.2.3.12 Strain Gauges and Load Cells and Pressure Gauges/Transducers

Early detection of the unacceptable strain conditions that precede structural failure in hardware is critical. Discrete strain gauges (load cells) -- typically four wire resistors connected together -- have been successfully used and are well understood for measuring loads on structures and tensions in mooring lines. These gauges help to distribute the load on mooring lines and measure the strain on winches and mooring components. However, strain gauge arrays have a number of shortcomings when applied to large structures, including cost, reliability, and wiring requirements. In marine environments, where the potential exists for water intrusion, sensor damage and ambient noise further complicates their use.

In response to problems inherent in strain gauges, continuous-fiber-optic strain-monitoring systems have been utilized. This technology already has been successfully applied to the structural monitoring of subsea pipelines, offshore structures, and ship hulls.

6.2.3.13 Ultrasonic Guided Wave

Ultrasonic guided wave (UGW) technology offers improvements over point-to-point ultrasonic thickness readings facilitating the rapid inspection of large sections of piping over long distances.

6.2.3.14 Ultrasound

Ultrasound and ultrasonic methods for the inspection of welds, thickness measurement to determine remaining wall thickness due to the corrosion as well as cracking and anomalies in subsea ferromagnetic materials.

6.2.3.15 Wave Radar

Wave radars provide information similar to ADCPs and are useful in the collection and analysis of wave spectra.

6.2.3.16 Weather Monitoring

In-situ weather monitoring plays an important role in understanding and optimizing device performance under a range of conditions as well as in forecasting and determining when appropriate shut-down conditions exist on site. Winds are most important, but a full weather station with wind speed and direction, atmospheric pressure, air temperature, relative humidity, and solar radiation will provide local information which can be used for local weather prediction, while also being useful in developing global weather models and improving regional weather predictions.

Chapter 7. Electrical Transmission and Interface

7.1 State of Electrical Transmission and Interface Technology

Subsea electrical power transmission – unquestionably one of the most costly aspects of implementing offshore marine energy – is supported by a well established industry with manufacturing, installation, inspection, and maintenance infrastructures generally in place. Indeed, the subsea cable industry eagerly awaits offshore renewable energy initiatives. (See exhibit 7.1.) Electrical transmission and interface challenges do exist, of course, because of the severe offshore environment; the many unknowns about wave and current energy conversion system implementation, operation, and maintenance; and the technical hurdles involved in the transmission of power from wave or current energy conversion devices to the sea floor, where it can be connected with standard undersea cables.

Exhibit 7.1. Cable-installation vessel. Note remotely operated vehicle suspended from the aft gantry.[26]

Although the each project is different, the following recent estimates and approximate cost data of some underwater power projects give an indication of the substantial costs associated with the construction of subsea electrical infrastructure:

- $150 million to construct a 53-mile undersea high-voltage direct current (HVDC) cable between San Francisco and Pittsburg, California ($2.8 million per mile).[27]

- $600 million to complete a 65-mile undersea HVDC power transmission system from Sayreville, New Jersey, to New Cassel, New York – 50 miles subsea and 15 miles on land ($9.2 million per mile).[28]

- Cape Wind considered several different options for grid interconnect, including: The $80 million Barnstable interconnect, with a 19- to 24-mile transmission line, 9- to 12-miles subsea (at least $3.3 million per mile). The $127 million Harwich alternative, 21 miles, 17 subsea ($6.0 million per mile). The $129.2 million New Bedford alternative, 32 miles subsea ($4.0 million per mile).[29]

The installation and maintenance costs of submarine cable required by offshore wave or current energy conversion is substantial, certainly on the order of $3-5 million per mile. This outlay will be a critical

[26] http://www.mbari.org/
[27] Contract awarded to Siemens Power Transmission and Distribution by Trans Bay Cable, LLC.
[28] The Long Island Power Authority/Neptune project, in cooperation with Siemens and Prysmian Cables and Systems. The cost includes more than the subsea cable alone and is therefore not a reliable indicator of the basic cost of subsea power transmission.
[29] Other options were considered as well.

factor in determining the size, scope and financial feasibility of these ocean renewable energy projects. (See exhibit 7-2.)

Aside from cost, another concern in undersea power transmission is the condition and suitability of the electric power transmission system in the United States for offshore renewable energy. Accessibility to the shore-based infrastructure is critical; the greater the transmission distances required, the less feasible a project will become.

Exhibit 7.2. Remotely operated vehicle for subsea cable operations.[30]

Concerns about potential environmental impacts from electromagnetic fields caused by power transmission lines are not expected to be problematic. The extremely long wavelengths of low-frequency (60 hertz) fields carry little energy and cannot break chemical bonds or heat living tissue. As such, they generally are not considered an environmental risk. (In the case of Cape Wind, a siting board accepted “edge of right of way” levels of 85 mG for magnetic fields.)

The first subsea HVDC cable was installed in 1954. Some debate exists over the pros, cons, costs, and considerations of alternating current (AC) versus direct current (DC) power transmission. Economically, distance is a critical factor in the selection of DC over AC for power transmission, with AC less costly at shorter distances. DC power transmission also facilitates improved load flow, peak supply, stabilization, and controllability. While AC power transmission has been very successful with widespread use, technical and economic forces can make HVDC a preferred alternative to AC. The advantages of HVDC include:

- Economic power transmission over very long distances.
- Power transmission between networks operating asynchronously or at different frequencies.
- Input of additional power without increasing the short-circuit ratio of the network
- Superior ability to move large blocks of power over long distances without requiring the high charging current of AC systems.

We expect that both AC and DC systems will be used for offshore generation of electricity, depending entirely upon the circumstances of the installation – with distance from shore the most defining factor.

7.2 Electrical Transmission and Interface Inspection and Monitoring

Many subsea power cables options are available for a given application. Subsea cables typically consist of several layers, including conductors, insulation, sheath, and armor. Some cables are fluid filled. Transmission losses, strength, thermal resistivity, power quality, splicing and harmonic content in voltage and current waveforms are critical issues. Manufacturing technologies now make it is possible to

[30] BBC News, December 23, 2008.

manufacture single- and three-conductor transmission cables in continuous lengths up to 100 kilometers, minimizing the need for joining cables.

The installation of subsea cable itself presents challenges and raises implementation issues. Cables must be strong enough to withstand the huge mechanical forces they are exposed to during installation from their weight and from hydrokinetic currents. (Strong currents, of course, would be desirable for most offshore energy conversion.) The need for inspection and monitoring activity may be greatest during installation; once a cable is laid, typically the inspection requirement are minimal, but will vary from installation to installation. Since wave and current energy conversion installations most likely will consist of multiple devices, as depicted in exhibit 7-3, the greatest inspection requirements will be placed on network connections.

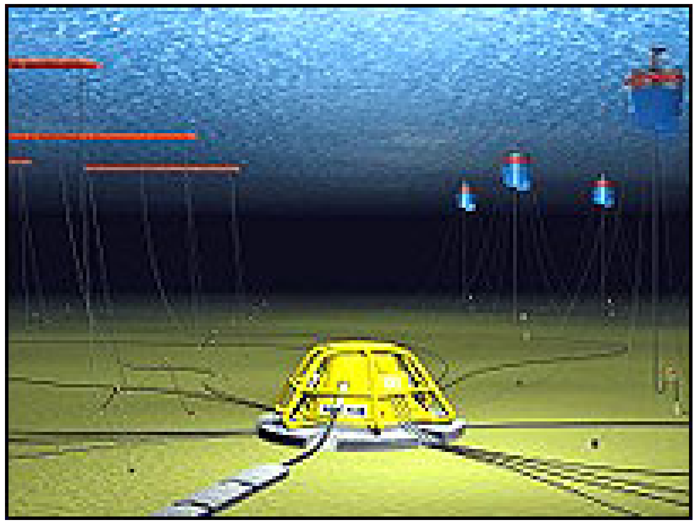


Exhibit 7.3. Artist rendition of subsea electrical hub connection.[31]

Subsea cable often is buried because of the risk of damage from commercial fishing activities, impact with vessels, platform movement, and anchors. Depending on the bottom, jetting, plowing, or trenching might be employed to bury cable. Burial depths typically range from 50 cm to 1.5 meters, but can be greater. For example, the recent Long Island Power Authority/Neptune RTS cable was buried between 1.2 meters deep (outside navigational channels) to 5 meters deep (within navigational channel crossings). The development of remotely operated vehicles (ROVs), cable burial systems, and computer-controlled dynamic positioning systems has greatly advanced the ability to install and maintain subsea cable systems.

Inspection methods for subsea cable include side-scan sonar, infrared measurements and ROVs. The power, of course, is monitored continually from shore. In general, once power transmission cable has been installed, the risk of breaks and damage are greatly minimized, with buried less likely to suffer damage than cable laid on the surface.

Siting and regulatory issues for marine energy electrical transmission and interface are complicated by several critical factors, including distance, cost, environmental impact, related regulatory requirements and the condition and capabilities of the grid tie in. Accordingly, multiple transmission routes and landing points are typically evaluated. Although subsea cable systems avoid many of the right-of-way issues associated with land-based power transmission, developers must focus on potential impacts on navigation, possible damage from commercial fishing activities, and crossing existing utility easements for power transmission and communications. Pilots associations, the U.S. Coast Guard, and the U.S. Army Corps of Engineers are some of the stakeholders involved in the decision making and regulatory approval process. Landing power involves identifying and meeting the regulations and requirements of states and local utilities. Historically, after many installations and after extensive environmental testing before, during, and after construction, subsea power transmission has been proven to be environmentally

[31] Wave Hub: http://www.wavehub.co.uk/. Industrial Art Studio Ltd, St Ives, Cornwall: www.ind-art.co.uk.

friendly. The greatest environmental concern appears to be focused on shellfish resources impacted by trenching required to bury cable.

The International Council on Large Electric Systems (CIGRE), which addresses the technical, economic, environmental, organizational, and regulatory aspects of large power systems worldwide, maintains study committees, working groups, and task forces to provide technical and regulatory guidance on a broad range of topics relevant to large electric systems.[32] The International Electrotechnical Commission (IEC) has many technical committees and subcommittees devoted to various aspects of subsea power transmission and cables.[33] The European Marine Energy Centre (EMEC) also is focusing on electrical transmission and grid connection issues.[34]

[32] Several CIGRE documents are particularly important: "Methods to Prevent Mechanical Damage to Submarine Cables" (CIGRE paper no. 21-12), "Reliability of Underground and Submarine High Voltage Cables" (paper no. 2-07), and "A Survey of Installation and Repair Techniques Presently in Use for Submarine Cables" (paper no. 21-202).
[33] IEC 60227 pertains to cables rated up to 450/750 volts, while IEC 60228 is the international standard on conductors of insulated cables. Committees developing pertinent standards include IEC TC 18 "Electrical Installations of Ships and of Mobile and Fixed Offshore Units," SC 18A "Cables and Installations," and TC 20 "Electric Cables."
[34] Section 2 of the EMEC draft "Guidelines for Grid Connection of Marine Energy Conversion Systems" for connection to networks at voltages below 132 kilovolts references technical documents, engineering standards, and recommendations pertinent to power transmission for marine energy.

Chapter 8. Structural

In this chapter, we relate existing standards, codes, and other practices to energy conversion device structures.

8.1 State of Structural Technology

In relatively shallow waters, monopoles of steel, concrete, and /or fiberglass-reinforce polymers (FRPs), permanently bottom fixed, are likely to be found. Further out at sea, spar and surface buoys are likely. Regardless of the deployment or technology, the most predominant structural materials are concrete, steel, and fiber-reinforced polymers.

8.1.1. Materials

Two materials have been used extensively in offshore structures: concrete and steel. Just in the past two decades, however, the industry has witnessed an increase in the utilization of FRPs for their inherent advantages. These structural materials also are subject to erosive and corrosive actions, but they should perform satisfactorily under dynamic cyclic and impact conditions in a wide range of temperatures.

8.1.1.1. Concrete

In a hostile environment such as seawater, special attention should be paid to ensure the long-term durability of concrete structures. Concrete durability is dependent on using appropriate design considerations (Eskijian 1997). In particular, it is paramount that designs consider the likelihood of crack propagation occurring when members are in service.

Structural concrete must conform to the best practices of concrete construction and codes (such as building codes) and recommended practices for bridges and marine structures. It is necessary to supplement the general requirements set forth by codes with recommended practices and rules for marine and offshore structures. Recommendations for durable concrete can be found in American Concrete Institute (ACI) publications (ACI 1984 and ACI 2004). These concrete mixes contain type II, low-tricalcium-aluminate cements as well as fly ash and/or silica fume to maximize their resistance to chemical attack by sea water. It is established that the following mix design parameters should be considered when designing concrete for the marine environment:

- Fly ash or silica fume increase the density of concrete, making it less porous and resulting in improved durability. Fly ash and silica fume raise the silica content to a level that prevents sulphate attack and increases the resistance to alkali-silica reactivity.
- Air entrainment improves freeze-thaw resistance of the concrete and aids in durability by providing an entrained volume for by-products from corrosion and chemical reactions.
- Corrosion inhibitors, such as calcium nitrite, can be effective, although their long-term effectiveness is still under study.
- Water reducers are commonly used to reduce water/cement ratios and also to increase the workability of the concrete. A lower water/cement ratio reduces permeability.
- Anti-washout admixtures are used for underwater construction to minimize segregation of the components.

The reinforcement popularity of using noncorrosive fiber-reinforced polymers (FRP) has, in the past decade, soared for applications where chemical corrosion poses a problem to structural members. A recent edition of the design guide published by ACI presents the guideline for design of these members.[35]

The successful use of concrete decks pre-stressed with carbon fiber strands have been also reported with longer periods of durability.

8.1.1.2. Steel

Steel has served the offshore and shipping industry well in routine and very demanding applications. Since steel is subjected to external corrosion, durability of steel members has been of high importance.

The American Institute of Steel Construction (AISC), the American Petroleum Institute (API), and Det Norske Veritas (DNV) classified steel materials and their use limitation in their standards documents.

ASTM A-36 and API 2-H are still the primary metal grades used in the construction of most offshore platforms. Frequently other intermediate-strength (50 kilopounds per square inch) steel is used in place of 2-H where the through-thickness properties are not required. In instances requiring extra thickness or for more highly stressed or critical applications, special quenched and tempered steels, such as API 2-Y, have been utilized.

Fabrication and welding of steel members should be carefully qualified through a variety of methods. Nondestructive testing (NDT) and mechanical tests are generally required for steel structures. Fabrication of offshore structures should follow applicable provisions of codes and standards, such as API-RP2A and AISC specifications, for the design, fabrication, and erection of structural steel.

Steel is a standard material used in larger offshore structures. Painting and active cathodic protection have provided long life. Chain moorings with active cathodic protection also can achieve longer life. On a taut mooring where the chain has no possibility of going slack, electrical contact is maintained between links, allowing cathodic protection to work; however in single-point, chain-catenary moorings, such as those used in research and observatory moorings, two years is the typical expected life without this protection. Zinc-coated chain may increase its life somewhat, but not significantly.

8.1.1.3. Composites

Composites – also known as FRPs or advanced composite materials (ACMs) – combine fiber and a binding matrix to maximize specific performance properties; neither element merges completely with the other. Advanced composites utilize only continuous, oriented fibers in polymer, metal, and ceramic matrices.

Composite FRPs offer the energy conversion devices, support structures, and offshore engineering industries new ways of cutting costs and improving the durability of construction, especially for structures in contact with sea water (Martin 1996). The primary advantages of FRPs are their good corrosion and chemical resistance, low maintenance, and high strength-to-weight properties. Other advantages that composite materials offer energy conversion devices and their structures include:

- Corrosion and chemical resistance
- Low weight

[35] ACI 440.1R-06.

- High strength
- High stiffness
- Fatigue resistance
- Low thermal conductivity
- Low electrical conductivity
- Electromagnetic transparency
- Easy installation (handle/cut I mill, etc.)
- Low flow friction and wear
- Design flexibility
- Integration of electrical and information transmitters into the laminate walls for protection and structural monitoring

Increasing the use of FRPs in offshore structures will require a higher level of confidence in their safety and durability. Currently, no general design procedure exists that will ensure long life, but a number of methods are available that if correctly applied can meet the needs of the composite material designer to determine durability and strength of the composite materials and structures.

FRP composites members are fabricated using different techniques, depending on the case merit. Techniques include compression moldings, injection moldings, hand lay-ups, and pultrusions. Sandwich members are typically more complex and expensive when compared to laminated counterparts, but they offer higher flexural rigidity and lighter weight. Testing of sandwich members is performed in compliance with ASTM Standard C 273-00, "Standard Test Method for Shear Properties of Sandwich Core Materials," and ASTM Standard C 393-00, "Standard Test Method for Flexural Properties of Sandwich Constructions."

Fiber ropes, composite materials, and plastic construction will eliminate problems associated with corrosion and allow much longer life in the structure and mooring. However they often have their own problems, such as changing size with the absorption of seawater.

8.1.1.4 Other Metals

Other metallic components, such as titanium and aluminum, have been used for offshore structures and moorings. In aluminum structures, high-zinc-content components, such as used in 7074 high-strength aluminums, are especially subject to corrosion, even when protected with zincs or active catholic protection. Lower-zinc alloys, such as 6061, are often used in surface structures and are subject to corrosion even with anode protection. Lower-strength alloys, such as the 5000 series (often used in ship superstructures), are best and can easily be protected with zinc anodes, however, they don't have the strength of steel.

8.1.2. Design Criteria

Many standards addressed the design criteria of offshore structures. ISO 19900 addresses the standards for oil and gas offshore installation design requirements and might provide the core of standards to use to the energy conversion device structures:

ISO 19900	General Requirements for Offshore Structures
ISO 19901-1	Metocean Design & Operating Considerations
ISO 19901-2	Seismic Design
ISO 19901-4	Geotechnical Foundation Considerations
ISO 13819-2	Fixed Steel Structures

ISO 19902	Fixed Steel Offshore Structures
ISO 19903	Fixed Concrete Offshore Structures
ISO 19904-1	Floating Offshore Structures

API has introduced a series of guides and bulletins for design and operations of offshore structures, API-RP2A.

Continuous inspection and monitoring of installations has resulted in increased safety of structures and operations over the years (MMS 2007). A recent report prepared for MMS concluded that most of the destroyed platforms were older vintage structures of 1960s or 1970s design, a time when there was little or no industry guidance on how to properly design a platform. Other findings were new to hurricanes Katrina and Rita, such as the destruction of newer generation platforms installed in the year 2000 or later. Appendix B summarizes some of the existing relevant design standards from API and other international organizations that address the design of offshore structures.

8.1.3. Survivability

Because they likely will be unmanned, the design of offshore energy conversion devices and structures should be balanced by two factors: the necessity of protecting personnel (when present) and the need for the system to survive extreme events and conditions. When defined properly and early in the design stage, survivability limit usually is an important factor for the manufacturer's reputation, as well as an important factor in the protection of capital investment. As mentioned in section 8.1.5, however, safety can be set at levels that can impact fatigue aspects and other deterioration mechanisms.

The industry is still at its infancy in terms of standards development for energy conversion devices. A study published by British Maritime Technology (BMT) Cordah Limited for the European Marine Energy Centre (EMEC) stated that "no definition of survivability has been found in national or international standards' for energy conversion devices (EMEC 2008). Exhibit 8-1 shows the relationships of the developing standards to product and industry development.

In general, the degree to which levels of protection can be afforded will depend on the willingness of industry to make sacrifices in service interruption and on the economic constraints within which the industry operates. Such decisions are crucial at planning and design stages of energy conversion devices, in contrast to manned platforms or installations where lives might be at risk in case of failure.

In its recommendation to EMEC, BMT distinguishes two aspects of survivability:

- Safety Survivability: The probability that the converter will stay on station over the stated operational life.
- Functional Survivability: The probability that the converter will produce its rated energy (or allowed degraded energy rating) during the stated operational life without damage that leads to major unplanned removal or repair.

Issues to consider when addressing survivability include:

- Ability to survive extreme events, such as major storms and peak waves.
- Ability to survive long-term conditions, such as cumulative battering of waves, the corrosive impact of the marine environment, and fatigue.

Exhibit 8-1 shows an EMEC diagram of renewable energy standards relationships.

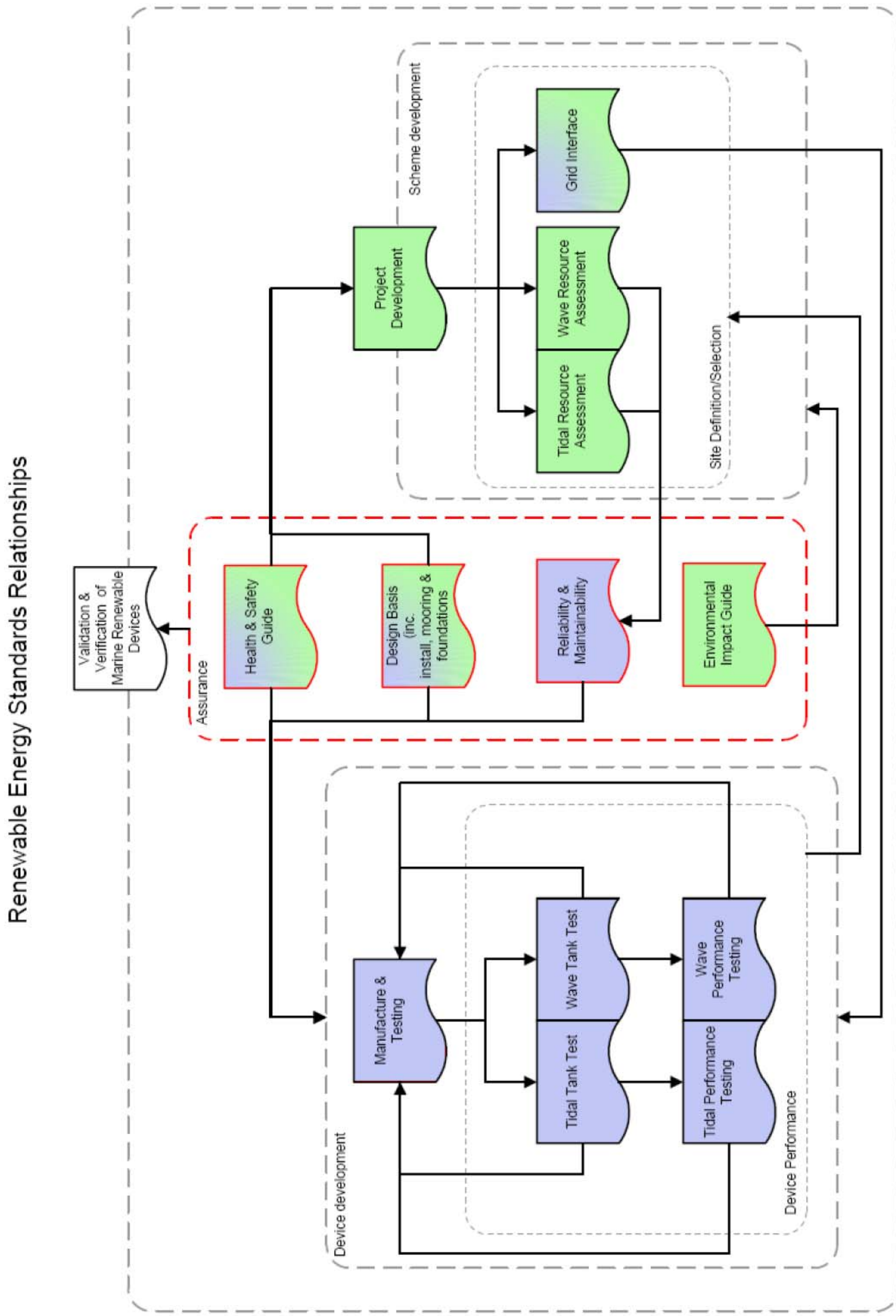
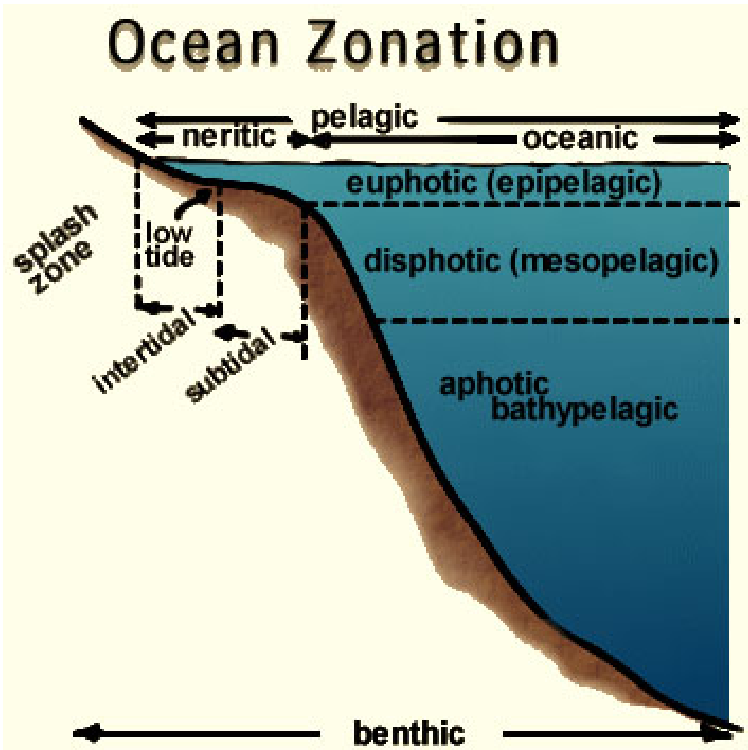


Exhibit 8-1. Relationships of marine energy standards.[36]

[36] European Marine Energy Centre.

8.1.4. Splash-Zone Protection

For offshore structures, the intertidal zone, including the splash zone, is worthy of particular attention with regard to the deterioration of structural elements. (See exhibit 8.2.) In particular, the splash zone is known to be aggressive in its effect on structural members and their materials.



Design loads in the splash zone are usually determined using model tests or computational methods where simplified formulations or empirical relations for added mass and damping are considered. One recent study reported a good correlation between observed and computations (Buchner and Bunnik 2004).

Exhibit 8-2. The intertidal splash zone demands particular design attention.[37]

8.1.4.1. Concrete

While the submerged zone and the zone below mudline (unless drained) zone show low risk for concrete members, the splash and atmospheric zones show high susceptibility to carbon dioxide corrosion of the reinforcement steel. In these zones, concrete members are subject to cooling and heating and wetting and drying effects. Conventionally reinforced concrete shows a reduction of fatigue resistance and endurance due to high pore pressure in the micro cracks. To resist fatigue under high-cycle, fully-reversing loads, such as waves, pre-stressing can be effectively used. Pre-stressing – by keeping the concrete always in the uncracked range – effectively resists degradation due to cyclic loading.

The key properties of modern, high-performance concrete, properly reinforced and pre-stressed, include:

- High compressive and tensile strength
- Durability in the marine environment

Durability – which can be achieved by using adequate concrete cover plus coatings or the use of cathodic protection – has been reported to give a durability of up to 100 years (Gerwick 1997). Exhibit 8-3 shows a typical concrete piling installation.

[37] Canada Aquatic Environments.

Exhibit 8-3. An offshore structure supported on concrete pilings.

8.1.4.2. Steel

Research shows that high corrosion rates are experienced by steel in the splash zone due to the combination of highly aerated water and erosion. (See exhibit 8-4.) Cathodic protection has not proved to be effective in this area, which has necessitated the use of other types of protection. According to research, a nickel-copper alloy, UNS 04400, has been successfully used for many years in splash-zone applications. Also, UNS C70600, a 90-10 copper nickel alloy, has given excellent service for 12 years welded onto legs in stage one of Maracaibo Field (British Gas). In addition, divers' inspection has revealed reduced fowling on the 90-10 alloy sheathing (Powell and Peters 1997.).

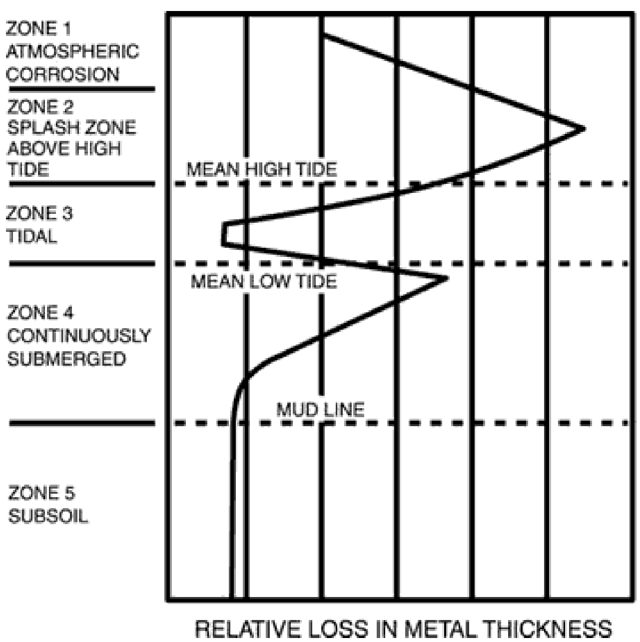


Exhibit 8-4. Metal thickness losses vary with atmospheric exposure.

8.1.4.3. Composites

The inherent lower weight and corrosion resistance of composites gives these materials significant advantages when compared to steel. Some of the technical barriers to the use of composite materials in offshore structures include:

- A lack of design standards and data for composite structures in offshore applications
- Unfamiliarity in the offshore industry with composite fabrication technology
- A lack of reliable and well understood nondestructive testing methods for composites
- Concerns about the long-term durability of composites, particularly with respect to fatigue and impact loads
- Concerns about the fire resistance of composites

Even with these many technical barriers, composite materials do exhibit strong potential for increased application in marine structures. For example, the low weight/high mechanical properties of these materials can be exploited to produce rugged, lightweight structures. An all composite platform is shown in Exhibit 8-5.

Exhibit 8.5. All-composite platform.[38]

Likewise, the high stiffness of carbon fiber composites can be exploited in both strengthening and repair applications to create new load paths in selected areas, thereby allowing for more efficient use of traditional materials. Such hybrid solutions are likely to lead to both cost and weight savings.

8.1.5. Fatigue Capacity

The fatigue capacity of a structure is defined as the structure's ability to withstand cyclic loading. Improving the yield strength of the material will, as for the E-modulus, not improve the fatigue capacity of the materials. In design stages, the structural reliability for fatigue strength under nonlinear and irregular wave-induced load should be considered numerically and experimentally.

8.1.5.1. Concrete

To resist fatigue under high-cycle, fully reversing loads, such as waves, pre-stressing can be effectively used. By keeping the concrete always in the uncracked range, pre-stressing effectively resists degradation due to cyclic loading. Exhibit 8-6 shows cracks in concrete caused by fatigue.

Exhibit 8-6. Fatigue due to cyclic loading caused cracks and spalling in concrete.

[38] Strongwell.

8.1.5.2. Steel

The most important tools in defining the fatigue capacity of a structure are the SN curves, which give number of cycles until damage occurs at a given dynamic stress level. SN curves are normally worked out for the parent material and a set of welded structural details. It is now established that steel fatigue can be avoided if the dynamic stress level is below the given limit. The use of higher-strength materials increases the static and dynamic stress levels, thus a structure will be more exposed to fatigue loads.

Post treatment of welded joints also may improve the fatigue capacity of a structure. Research and development projects within these fields have shown that the effect of grinding and hammer preening is promising. SN curves close to the parent material curves have been reported from some of these projects. Since the fatigue strength of a welded structure is not improved by increasing the strength of the steel, if a fatigue-loaded structure is slimmed down in connection with the use of high-strength steel and welded as usual, without duly considering the implications of the higher stress level in the structure, fatigue problems may arise.

Selecting high-strength steel for the purpose of reducing the material thickness generally leads to a higher stress level. It is therefore recommended to pay special attention when using high strength steel in fatigue loaded structures.

8.1.5.3. Composites

For FRPs, the fatigue capacity can be defined in the same way as for the metallic materials. However, as the materials can change very much from one application to the other, the need for special fatigue testing is obvious. Such testing is expensive and time consuming and can be a further obstacle in using sophisticated, high-strength, fiber materials.

Some fatigue data for commonly used FRP are available, to some extent. The fatigue capacity of the individual fibers is normally very good, but combined with the different fiber directions and the resin, and whether core is used or not, the fatigue capacity is reduced and can only be established by fatigue testing.

8.1.5.4. General Recommendations

Techniques that may be useful to consider for improving the fatigue performance of a structure include:

- Deliberately locate welds away from areas with high dynamic stresses
- Consider using cast or forged components
- Consider post-weld treatments, such as grinding weld-toe regions

With regard to post-weld treatments, fatigue is a local phenomenon. All factors leading to a reduction of local stress concentrations will improve the fatigue life of that region. To this end several types of post-weld treatments are available.

8.2 Structural Inspection and Monitoring

8.2.1 Summary of Existing Regulations and Standards

Concern for potential harm to humans, potential damage to the environment, and the assurance of profitable, unimpeded, extraction of energy offshore is a concern of lease grantors and investors, as well as operators. Typically, the requirements for underwater inspection of offshore structures and the techniques and tools to conduct such inspections vary widely from country to country and from standards to standards. In some instances periodic inspection is required by law; in other instances, there is no requirement whatever once a structure has been installed.

The instruments to conduct underwater inspections also vary, their effectiveness is sometimes questionable, and the cost of underwater inspection to the operator (ultimately borne by the consumer) is high and will get higher as the water depth and complexity of the structure increases.

A list of candidate standards appears in appendix B.

8.2.2 Best Practices

Monitoring and Inspection of offshore energy conversion devices and their structures will be a sophisticated and expensive process. Due to the wide variety of devices in terms of configuration and location with respect to water column, we recommend a flexible approach to monitoring and inspection on a fit-for-purpose basis.

Proper planning and implementation of monitoring and inspection have the following merits:

- Confirmation of the continued integrity of the installation structural and mechanical components
- Identification of potential problem areas
- Avoidance of structural or mechanical collapse
- Avoidance of production shut-down.
- Avoidance of pollution
- Compliance with local regulations
- Ability to extend the design life of the installation
- Establishment of design criteria for any additional construction or repair work

8.2.3 Existing Protocols

In 2004, API issued RP75, "Recommended Practice for Development of a Safety and Environmental Management Program (SEMP) for Offshore Operations and Facilities." This recommended practice is a fit-for-purpose tool for integrating safety management into a variety of offshore operations.

The first comprehensive safety and environmental management standard of its kind in the world, RP75 reflects the contributions of many industry offshore safety and operational experts with a combined hundreds of years of experience in the oil and gas industry; government agencies, such as the Minerals Management Service (MMS) and the U.S. Coast Guard; and industry trade groups, including API. The program was created to cover activities, procedures, and operating hardware. It was designed to be flexible and responsive and to be a permanent part of a company's culture, objectives, and operations. Many offshore operators and contractors, including all API oil company members, have created safety and environmental management programs that follow the recommendations in RP75.

SEMP starts with an assessment of operating and design requirements and a hazards analysis. It requires establishment of safe operating procedures, work practices, management-of-change procedures, and associated training. It calls for procedures that ensure that the design, fabrication, installation, testing, inspection, monitoring and maintenance of equipment meet safe (minimum) standards. In addition, it recommends periodic auditing of safety programs and requires emergency response and incident investigation to help mitigate harm and prevent future mistakes.

It is noteworthy that a few attempts have been made to encompass API and International Organization for Standardization (ISO) inspection codes. A Joint Industry Project lead by Justin Bucknell of the MSL Services Corp. describes in detail an ISO system Structural Integrity Management (SIM) process that promises the application of both API and ISO inspection codes of platforms (Bucknell 2000). The paper shows improved platform integrity assurance and substantial safety, environmental, and economic benefits.

8.2.4 Recommended Inspection Methodologies

So far there is no standardized method of inspection for wave and currency energy devices. However, with some limitations, some of the existing inspection methodologies employed for the oil and gas industry have direct applicability for wave and current energy conversion installation inspection, depending on the given installation.

Chapter 9. Anchoring and Mooring

9.1 Anchoring and Mooring Technologies for Wave- and Current-Harvesting Buoys and Platforms

9.1.1 Overview

Wave and current energy harvesters for floating buoys and platforms are used for two electricity-generating applications, each with its specific mooring system, components, and suitable anchors:

- Generating electricity for "internal" use
- Generating electricity to export to the power grid

Autonomous wave energy harvesting buoys and platforms produce electrical power for use by the floating platform's sensors and to transmit/receive communications to/from shore via radio-link or satellite. The moorings used to secure and position these platforms are purely mechanical, usually a single-point mooring connection between the anchor and surface buoy or platform. A number of single point mooring techniques have been developed for these platforms, based on the mooring site's water-depth, including chain-catenary, S-tether, and taut moorings. Large platforms, such as floating oil-rigs and large ships, require multi-leg moorings. All of these moorings reflect significant development progress, although none have electrical linkages to the sea floor.

Shore-linked wave energy harvesting buoys and platforms deliver electrical power to shore via a subsea cable. The moorings used to secure and position these structures serve as both a mechanical link to the anchor and an electrical link to a junction box on the sea floor or mounted on the anchor. The power transmission cable connection to shore connects at the junction box.

9.1.1.1 Complex Mooring Challenges

Moorings for buoys and platforms with cable links to shore are considerably more complex and risky than moorings without cable links because of the difficulty of constructing electrical conductors that will survive in the highly dynamic surface-wave environment. The copper conductor in the electrical link to the subsea junction box has low elastic elongation (0.5 percent) and will not survive any significant stretching or bending. This property severely limits the type of electromechanical, rope-like strength member that can be used in the electrical link.

Steel-armored electromechanical cables, with elastic stretch of 0.5 to 1.0 percent, can accommodate an electrical conductor core stretch (with some added twist) and support mooring tensions. However, the low stretch of wire ropes and steel-armored cables makes them unfit to survive the continuous and large oscillating vertical distance changes between the sea floor and surface wave peaks and troughs, the dynamic loads associated with the response to the buoy's heave and surge motions, and the horizontal drag on the cable due to the currents.[39]

[39] To illustrate taut mooring stretch requirements, a 10 meter wave in a 40 meter mean water depth changes its water surface distance from the sea floor from 35 to 45 meters every 10-20 seconds in a storm event. If the mooring is taut and under near-zero load at the trough of the 10 meter wave, it would be 35 meters long. To reach 45 meters at the wave peak requires a 28.5 percent stretch. (Stretch requirements increase exponentially at water depths less than 40 meters.) If a 45 meter mooring cable is used, it would be taut at the wave peak and would have 10 meters of slack when the wave-following buoy is in the wave trough position. The slack mooring not only could contact the cable, but it also could move the cable on and off the sea floor and drag it along the sea floor, which could destroy the conductor link and probably the cable itself. In much deeper water, the elastic long-term

Mooring challenges addressed below include:

- The inability of steel-armored cables to stretch to absorb dynamic cable loads caused by surface waves
- The inability of synthetic-fiber-armored cables to stretch to absorb dynamic cable loads caused by surface waves in shallow water
- Necessary mooring tautness to avoid damaging the mooring's electrical conductor at the anchor and sea-floor interface
- Separate mooring connection and electrical cable link to sea floor

9.1.1.1.1 Stretch of Steel-Armored Cables

Because of the inability of steel-armored cables to stretch to absorb dynamic cable loads caused by surface waves, steel-armored mooring cables also are unable to absorb the dynamic shock loading caused by the rapid heave and roll motions of the surface buoy.[40] In storm seas, the heavy mass of the cable drops quickly during the rapid descent of the surface buoy or platform into a wave trough. Near the trough bottom, the descent of the buoy or platform suddenly slows and then reverses, as the buoy or platform is forced to move rapidly upwards during the approach of the next wave. Unless the mooring contains a strong shock-absorbing section right under the buoy, the continuous and severe shock loading of the heavy mooring cable by the rapidly rising surface buoy or platform – a motion cycle repeated every 10-20 seconds in storm seas – will destroy the mooring.

9.1.1.1.2 Stretch of Synthetic-Fiber-Armored Cables

Synthetic-fiber-armored cables have significantly greater stretch than steel-armored cables, nonetheless the stretch is insufficient to absorb the dynamic cable loads caused by surface waves in shallow water. Nylon rope, for example, the highest stretching fiber rope available, has about 9-10 percent elastic stretch under in-use load-cycling conditions. Nylon rope would have to be furnished with suitably arranged electrical conductors to become an electromechanical conductor link to the sea floor. The 9-10 percent working stretch would significantly reduce the shock loads in a shallow-water system, but this working stretch would be too small to accommodate the required system stretch for shallow-water deployments as a taut mooring. The large variations of vertical distance between surface wave crests and troughs in exposed storm seas require more significantly stretch from a taut mooring[41]. In deep waters (full ocean depths) nylon has been employed successfully as a mechanical mooring component in a taut mooring but without electrical conductors.

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stretch range of the mooring will eventually become sufficient. The mooring stretch of a sufficiently long mooring cable in a taut mooring deployment must permit the unavoidable mooring length increases and retractions within its working stretch to be survivable.

[40] Due to the rapid vertical heave motion, significant snap loads would occur when the buoy or platform, forced to rise in an approaching large ocean wave, suddenly lifts the heavy added mass of slack steel-armored electrical mooring cable. These snap loads often are a multiple of the quasi-static mooring tensions. The electromechanical mooring link to the buoy should avoid slack under all conditions since shock loads in steel armored cables are severe and destructive due to the cable's low working stretch. Also, the rapid reduction of cable tension during the surface buoy's descent into a wave trough increases the risk of forming kinks in the cable, rendering the cable useless.

[41] A mooring working stretch range also must accommodate the stretch resulting from horizontal mooring displacement from the drag of ocean current forces and wind pressure on a buoy or platform. Water-level changes due to tides have to be considered, also, as the water levels can significantly rise or fall under hurricane wind or longer-lasting storm events. Thus, the total needed working stretch in a taut mooring can be significantly larger than the already high wave-heave stretch.

9.1.1.1.3 Mooring Tautness

A taut mooring is the only way current state-of-the-art moorings can prevent contact with and damage to the electrical conductor at the anchor and sea-floor interface and guarantee a survivable electrical linkage to a shore cable. A large amount of elastic mooring cable stretch – somewhat like a bungee cord – is required for a taut mooring to be sufficiently pre-stretched at mean water. With sufficient stretch, the mooring cable can retract and still be under tension when the buoy is in a wave trough yet still extend sufficiently when at a wave peak. Concurrently, however, the conductor stretch has to be kept at or below 0.5 at all times.

9.1.1.1.4 Separate Mooring and Electrical Cable

The use of a mooring cable separate from a steel-armored electrical cable link to a junction box on the sea floor would be difficult, at best. This arrangement would require a power cable with sufficient scope and with distributed floating sections and heavy sections to avoid chafing contact between power cable, sea-floor, mooring cable, and junction box. The possibility of entangling the electrical cable with the mooring cable, nonetheless, would be a risk with ocean currents changing directions and wave motion at the surface. In addition, deployment would be tedious and challenging.

9.1.1.2 Complex Mooring Solutions

9.1.1.2.1 Shallow-Water Solutions

One shallow-water, single-point mooring solution for the electromechanical link between surface buoys and platforms and anchors encompasses a highly elastic and highly stretchable connection (bungee cords). As shown in Exhibit 9-7, this highly stretchable electrical coil-cord assembly employs a number of parallel rubber tethers, with one tether serving as the core (Irish et al. 2006). A successful buoy mooring of this design was launched in 2005 and retrieved after 8 months on station. Although no abrasive effects were observed, long-term survival of this arrangement needs to be proven.

Another solution, which uses a sufficiently long section of high-stretching tire-cord-reinforced rubber hose with embedded electrical conductors, has shown encouraging survivability and ruggedness. The electrical conductors are spiraled around and embedded inside the hose wall in a stretch-neutral geometry; the geometry can change and allow large hose stretch without stretching the conductors (Paul 2004). This design worked successfully for several years in mooring a feed buoy at an aquaculture site where power and communications between the fish cage and the surface buoy were required (see 9.1.6.2). Damage occurred because of failure of the mounting bolts – which tore out the connectors – rather than stretch damage to the conductors (Irish et al. 2007). This mooring was a tri-moor configuration (see exhibit 9-9), with one leg the stretch hose (used as an electrical path and to pump feed) and the other two legs bungee cords to help supply the required mooring compliance.

9.1.1.2.2 Deepwater Solutions

An experimental mooring link – consisting of a nylon fiber rope core, spiraled electro-optical conductors around the rope core, and an outer braided jacket – formed the base of a 3,000 meter mooring. In the upper 1,000 meters, the cable was protected with a plastic jacket containing aramid fibers to prevent fish-bite damage. The lower 500 meters were covered with a lightweight jacket that rendered the cable buoyant to avoid entanglement with the anchor and sea-floor. This cable successfully maintained electrical conductivity to a load cell at the anchor in a 13-month deployment off the California coast. The optical fiber link was interrupted in one of the terminations during deployment, but otherwise it was working when the mooring was retrieved. After separating the cable from the anchor with an acoustic release, the buoyant bottom section formed a knot at its interface to the unjacketed, heavier-than-water upper 2,500 meter section, apparently from rising quickly. Fish-bite attacks in the upper section made indents into the fish-bite protecting jacket but did not penetrate into the cable and caused no conductor damage.

This technology shows promise for deepwater applications but needs further development with larger conductors to meet the needs of alternate energy.

9.1.2 Buoy and Platform Anchoring and Mooring Systems

Anchors, which attach to or rest on the sea floor, are connected to moorings lines, which in turn are connected to structures – such as energy conversion device platforms. Anchoring/mooring systems differ widely (selected examples appear below), but to ensure safe and efficient mooring, each anchoring/mooring system must be designed to meet the requirements of the application within the constraints of the environment. A number of design considerations must be addressed with regard to anchoring and mooring offshore structures, which could operate on the surface, in mid-water (between the surface and the bottom), and on the ocean floor. The details of anchors and mooring lines are discussed below in separate sections.

Together with the required knowledge and experience of buoy technology (such as Berteaux 1991), other knowledge is essential in developing reliable and survivable mooring systems for wave-harvesting and current-harvesting buoys, including:

- Familiarity with anchor technology
- Testing results of the sea floor soil properties for anchor holding potential
- Testing the selected anchor for holding power with nearly horizontal and nearly vertical pull directions
- Practical experience with the selection of suitable mooring components and connectors
- Corrosion protection of dissimilar materials in sea water
- Mooring assembly
- At-sea deployment and retrieval of buoy/moored systems

The applicant for funding of a wave generator platform should provide information and evidence of experience in the assembly of buoy systems and should submit a record and references of ongoing and completed mooring installations or evidence of using an established sub-contractor to moor and anchor the platform.

In general terms, three mooring components must be considered:

- Anchor
- Mooring line from the anchor to the structure
- Attachment points at the anchor and at the structure (weak points requiring special attention)

One common mooring configuration employs a drag anchor (tension at the anchor directed along the bottom), with a catenary of chain and rope (wire and/or synthetic rope) up to the structure, as shown in exhibit 9-1. For clarity, the oil-drilling platform mooring diagram shows just four anchors/moorings; a more typical platform will have 12 to 16 anchor/mooring lines distributed evenly around the platform.

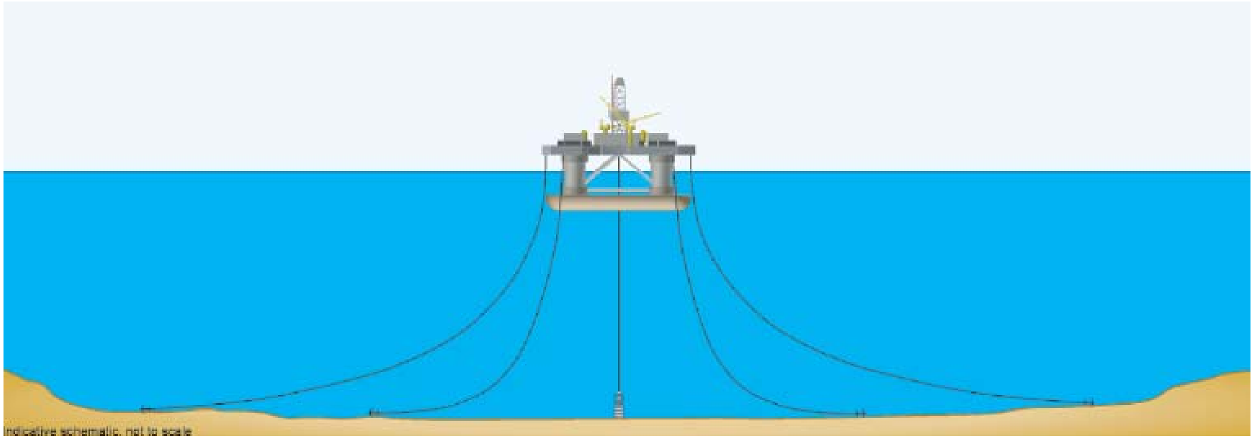


Exhibit 9-1. Schematic of a standard chain-catenary oil rig mooring with four anchors holding a surface platform in position (Woodside 2009).

The companies engaged in designing and deploying anchoring systems for floating oil platforms have developed thorough procedures to assure that the floating drilling platforms will maintain their positions safely. The safe position of a structure must be assured in all weather and wave conditions at a site to prevent anchor dragging or mooring component failure and – for oil platforms – over bending, which could fracture the drill string. Failure could be catastrophic, causing a pollution disaster, drifting of the platform with risk of collisions with other platforms, or stranding in severe weather. The result of failure would be large financial damages due to downtime, spill cleanup, platform repair, anchor resetting, mooring component refurbishing, and platform repositioning. For oil drilling, the maximum horizontal excursion is 5 percent of water depth; this excursion limit would not necessarily be a limit for wave or current generating platforms, but other limits, in particular breakage of the power cable to shore or overstretching and failure of its conductors, would apply.

A mooring configuration for one leg of a chain-catenary mooring of a large-surface platform (such as shown in exhibit 9-1) appears in exhibit 9-2. A platform might be moored with a number of these legs at each corner, and the wire rope might be replaced with a fiber rope or chain. Winches would be used to adjust the surface structure and to tension the legs, and tension in the mooring lines must be monitored to assure even distribution of load.

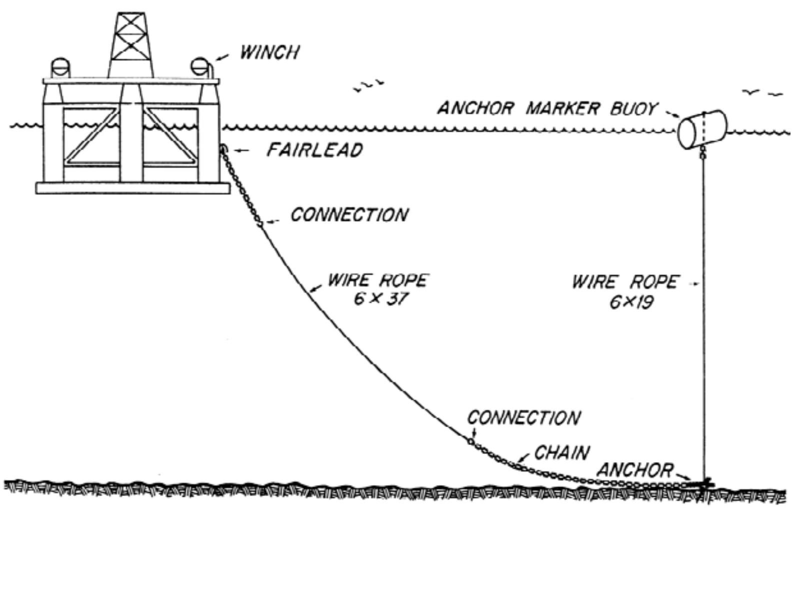


Exhibit 9-2. Mooring configuration for one leg of a

chain-catenary large-surface platform (Berteaux 1991).

Note that as the platform in exhibit 9-2 is moved by the tides, currents, waves, and wind, the chain near the bottom will be pulled off and dropped back onto the bottom. The connection of a power line from the surface platform to a junction box on the bottom (linking to a cable to shore) is impossible to construct so it will survive in this configuration. If the mooring were entirely chain, it would be limited to depths of 150 to 200 meters because the heavy weight of the suspended chain, which at this depth is equal to about 33% of its proof load. Although wire rope is considerably lighter than chain, it has a safe use of 3,000 meters at a safety factor of 5 due to the high weight of long lengths of wire suspended from the surface float.

The taut mooring or tension-leg mooring, an alternate configuration, appears in exhibit 9-3. Because the mooring lines rise nearly vertically from the anchor to the structure, deadweight or suction anchors (see 9.1.3.1 and 9.1.3.7, respectively), or a foundation constructed on the sea floor, generally would be used. In these moorings the compliance is added by incorporating a sufficient length of fiber rope into each mooring link. This fiber rope link must be selected and dimensioned to absorb wave-generated heave motions and the horizontal rig displacement caused by current and wind drag within the fiber rope's working load and stretch limits.

In the tension-leg platform shown in exhibit 9-3, vertical motion is reduced by using tendons to moor the platform, which is held up by the buoyancy in the platform. (Platforms tend to move sideways in a controlled manner.)

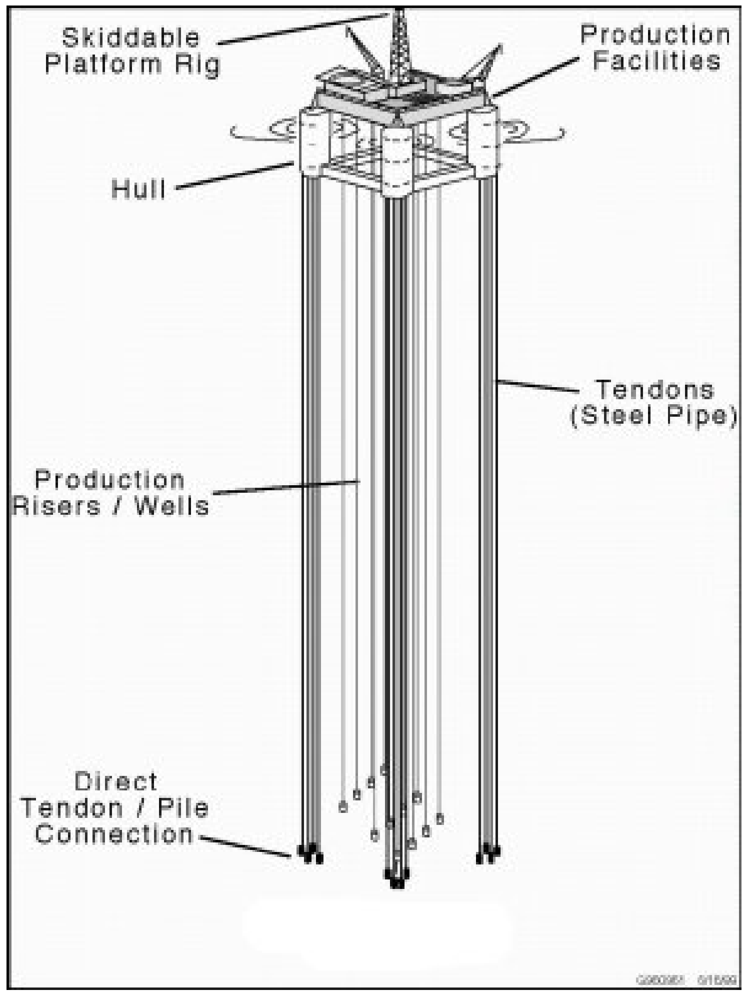


Exhibit 9-3. Mooring lines rise nearly vertically in the taunt mooring or tension-leg mooring configuration (Global Security 2009).

A number of different large moored platforms developed to extract oil from the ocean are shown in exhibit 9-4. The technology developed to moor these platforms could be applicable for wave and current energy harvesting platforms by adding a power cable to the sea floor.

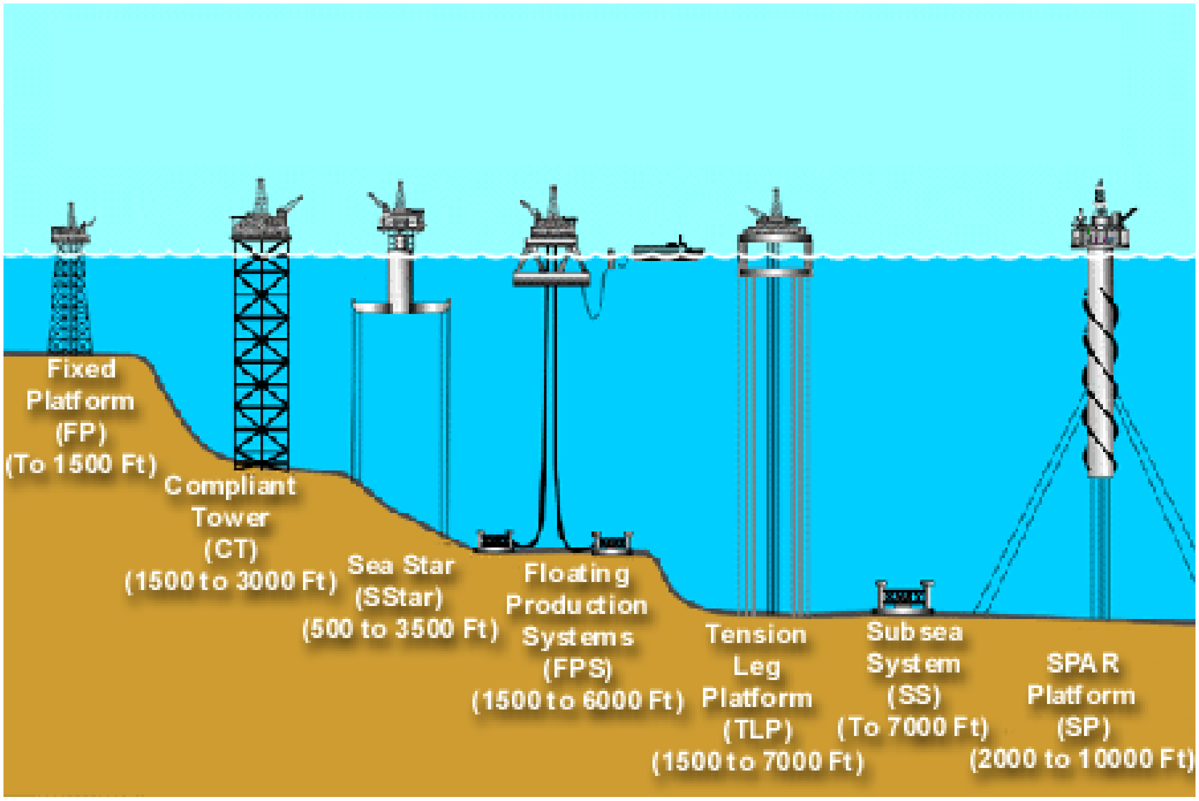


Exhibit 9-4. Fixed and floating platforms that could accommodate wave-harvesting devices (MMS 2009).

Scientific and observatory moorings (from shallow water to full ocean depth) have either surface or subsurface buoys/floats and may be good candidates for offshore alternate energy structures that need to be serviced regularly. Aquaculture moorings with a permanent grid of mooring lines with structures in the grid may be a good model for wave and current energy conversion devices moored underwater since the underwater equipment can easily be brought to the surface for servicing. (See exhibit 9-5.)

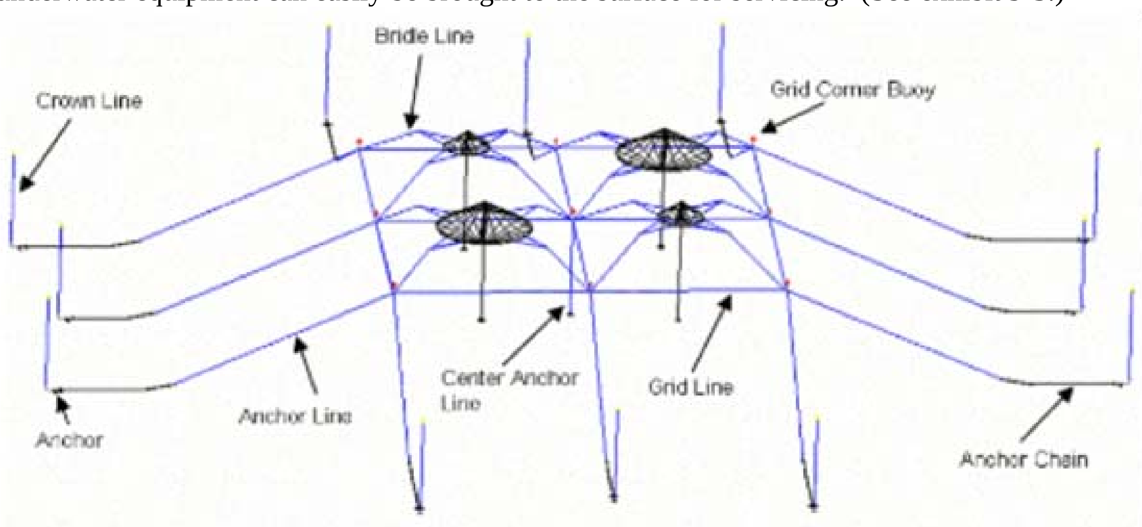


Exhibit 9-5. The grid arrangement of aquaculture moorings could be a good model for wave and current energy conversion devices moored underwater (Celikkol et al. 2009).

A representative single-point surface mooring with a chain catenary mooring line and deadweight anchor appears in exhibit 9-6. This configuration is typical of the U.S. Coast Guard aids to Navigation buoys found in coastal waters around the United States, as well as aids to navigation buoys around the world. The water depth limit for chain catenary buoys is about 35 to 40 meters, due to the heavy suspended weight of its anchor chain (NOAA 2009). The chain on the bottom must be heavy to survive dragging and being lifted on and off the bottom. In deeper water, the chain might only be used at the top and bottom of the mooring line, with a wire or fiber rope used in the water column. Connections for electric cabling cannot be made from the mooring because chain movement would cause cable wear and premature failure. Although the chain catenary and deadweight anchor mooring is a very mature technology, it is not applicable to alternate energy unless the energy is stored in some form (e.g., hydrogen) in the buoy and retrieved by service vessels.

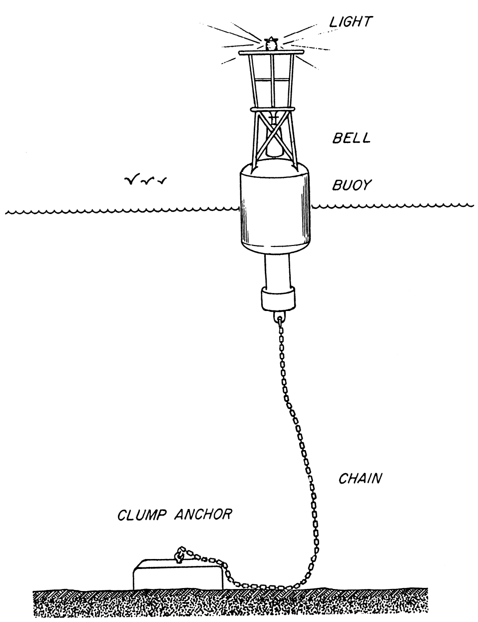


Exhibit 9-6. Single-point surface mooring with a chain catenary and deadweight anchor (Berteaux 1991).

A taut oceanographic mooring, as shown in exhibit 9-7, does not have the problem of the chain dragging on the bottom, and the shock tension in these mooring lines in a heavy sea tend to be lower than in the chain catenary mooring (depending on the number of sensors or weights in the mooring line). The main challenge with this mooring configuration is the compliant elastic tethers (bungee cords); although the tethers function well, they would have a problem carrying conducting wires from the top of the buoy to the bottom. Some solutions to his problem have been developed (Irish et al. 2006), but not yet for the high power of successful wave or current power generators. The swivel in the mooring – necessary to prevent the buoy from twisting the mooring line and causing premature failure – presents another challenge problem in a single anchor/mooring line configuration when connecting the surface buoy to a subsea cable.

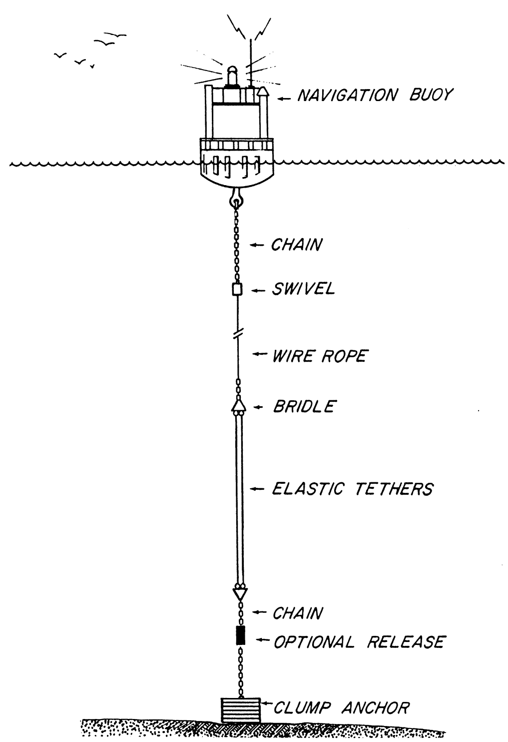


Exhibit 9-7. Taut oceanographic mooring (Berteaux 1991).

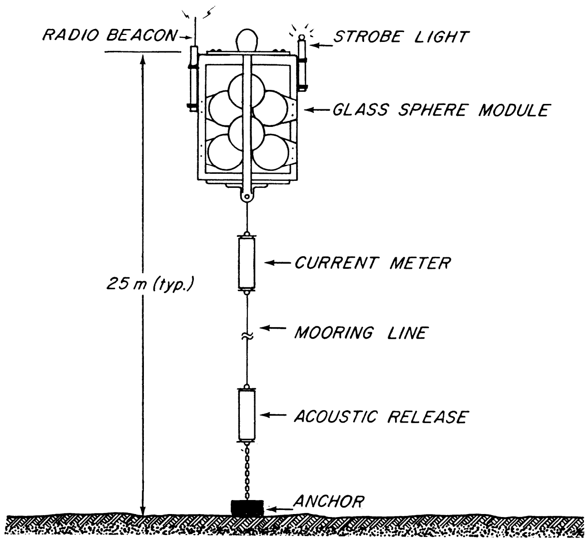


Exhibit 9-8 illustrates a subsurface scientific mooring with a single anchor and mooring cable. The flotation is below the surface, thus subject to less surface wave action. A conducting cable can be run from the instrumentation to the anchor and connected to a cable to shore. Note that this configuration doesn't have a swivel in the mooring line and could easily be connected to a bottom cable.

Exhibit 9-8. Subsurface scientific mooring with a single anchor and mooring cable (Berteaux 1991).

The subsurface configuration in exhibit 9-8 often has a bending moment at the flotation package and at the anchor that must to be considered in the design and inspection schedule. Raising the subsurface package/instrument to the surface for servicing could require disconnection from the electrical cable to shore by some kind of underwater connector, thus making the mooring system expensive and troublesome.

A tri-moor configuration for a subsurface mooring (see exhibit 9-9) doesn't have movement of the subsurface flotation with waves (reduced in amplitude with depth) and currents. This configuration has taut legs that do not move back and forth, making the connection to a bottom cable easier. This configuration is difficult to deploy, however, and compared with the subsurface mooring in exhibit 9-8, recover the top package for servicing is more challenging. Nevertheless, the tri-moor configuration does create a relatively "fixed" platform from which to measure current and waves.

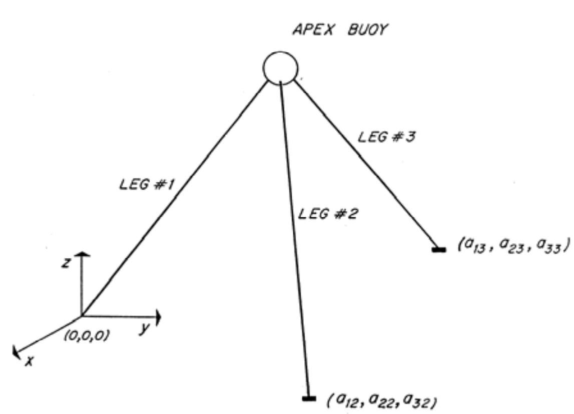


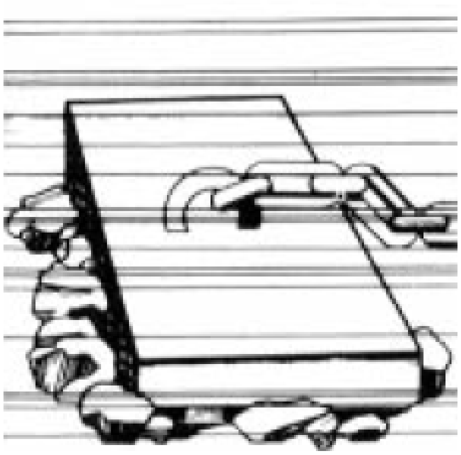
Exhibit 9-9. Tri-moor configuration on a subsurface mooring reduces the movement of the mooring with the waves (Berteaux 1991).

Note that the last four mooring configurations – single-point surface mooring with chain catenary, taut oceanographic mooring, subsurface mooring with a single anchor and mooring cable, and tri-moor subsurface mooring – use deadweight anchors (see 9.1.3.1).

9.1.3 Anchor Types

9.1.3.1 Deadweight

A deadweight anchor, the simplest form of a permanent anchor, is a large mass that sits on the sea floor and holds a structure in the desired position by its weight. (See exhibit 9-10.) Its holding power is defined by its underwater weight – its weight on land less the weight of the water it displaces – regardless of the type of sea floor. The holding power of a deadweight anchor is 45 to 50 percent of its dead submersed weight, although if it becomes buried in the sediment suction can increase its holding power. With a deadweight anchor, material density is a critical characteristic.



Deadweight anchors are used where mushroom, plow, and fluke anchors are unsuitable – such as on rock or gravel bottoms. The most common anchors used in scientific and navigational moorings, deadweight anchors are found on a wide variety of bottom types.

Exhibit 9-10. Deadweight anchor holds structures by weight (AMI 2009).

9.1.3.2 Fluke

A fluke anchor has a single or double fluke. When pulled, the anchor buries the fluke or flukes in the bottom (sand, mud, etc.) and holds the structure in the desired position by the amount of sediment covered by the fluke area buried in the sea floor. Fluke anchors often consist of a single large fluke attached to a shank that lays along the sea floor (see exhibits 9-11 and 9-12).

Exhibit 9-11. Large single-fluke anchors used to “permanently” anchor offshore structures (Delmar 2009a).

Four drag anchors similar to those shown in exhibit 9-12 have been used to moor a surface buoy in 55 meters of water with chain catenary moorings using fiber rope from the bottom to the buoy. Also, the submerged grid shown in exhibit 9-5 was moored with these anchors.

Exhibit 9-12. Medium-size single-fluke drag anchor designed for multi-anchor operations of a subsurface grid into which various structures might be inserted.[42]

The Danforth anchor, another kind of fluke anchor, is often associated with smaller anchoring needs, such as pleasure boats, although it is configured for larger loads, too.

The buried or inserted plate anchor, an alternative to the large, single-fluke anchor and the suction anchor, can be classified as a fluke anchor. This anchor essentially is a fluke stuck into the sediment so the pull is perpendicular to the plate, such as the SEPLA (Suction Embedded PLAte) anchor (see 9.1.3.6). The buried plate anchor, which depends on the geotechnical properties of the sediment for its holding power, is only effective in softer, unconsolidated sediments of uniform consistency. Plate anchors are an alternative to the large single fluke or the suction anchor.

Once well set into the sediments, the burying fluke anchor can develop an amazing amount of holding power. The fluke anchor has difficulty penetrating kelp and weed-covered bottoms, as well as rocky and particularly hard sand or clay bottoms.

9.1.3.3 Mushroom

Shaped like an inverted mushroom, a mushroom anchor relies on the head becoming buried in sediment for its holding power. (See exhibit 9-13.) A counterweight is often used on the top end of the anchor shank to lay it down before it becomes buried. Suitable for use where the seabed is composed of silt or fine sand, a mushroom anchor relies on suction and cohesion of the bottom material for its holding power (which rocky or coarse sand bottoms lack).

A mushroom anchor will normally sink into the bottom until it has displaced its own weight in bottom material. The holding power is at about twice its weight unless it becomes fully buried, when its holding power can be up to ten times its weight. The mushroom anchor is a familiar form of permanent boat anchor.

Exhibit 9-13. The mushroom anchor relies on the head becoming buried in sediment.[43]

[42] Photograph by James Iris, 2000.
[43] Seafarer/Sea Choice.

9.1.3.4 Dor-Mor Anchor

A very heavy, short, pyramid-shaped, cast-iron anchor with a short, heavy shank exiting from the square bottom of the pyramid (see exhibit 9-14), the Dor-Mor anchor is somewhat similar to the mushroom anchor. Its holding power depends on the sea floor, but the required breakout tension can exceed ten times the anchor weight when pulled nearly horizontally in heavy clay bottom.

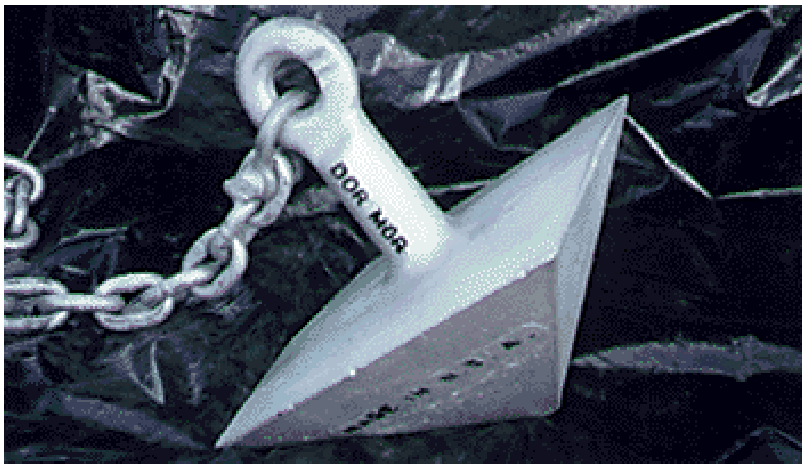


Exhibit 9-14. The Dor-Mor pyramid mooring anchor can require breakout tension greater than ten times the anchor weight (Dor-Mor 2009).

Dor-Mor anchor drag tests on a sandy seafloor at a 40 meter depth in Martha's Vineyard Sound near Menemsha showed the anchor responding in a slip-stick mode. The anchor was digging in and holding at a pulling-rope tension about equal to the anchor weight. The anchor stayed in place until the line tension doubled and then broke out and was dragged by the vessel. Once freed, the anchor dug in again until the line tension grew to twice the anchor weight, and then starting the slip-stick cycle again. If positioned in firm mud and possibly soft clay and then dragged, the anchor starts to move smoothly along with the pulling vessel when the line tension is equal to the anchor weight (similar to a spoon being pulled through a pot of thick honey) (Trask et al. 1999).

Earlier Dor-Mor tests, performed in 1997, compared the holding forces of deadweight steel anchors, Mace anchors (flat cylinder with bottom skiffs to increase resistance to horizontal pull), and Dome anchors (flat cylinder with rounded top to reduce tangling). The Dor-Mor anchor was selected to moor a long-line mooring (with a 45-degree line tension) since its weight efficiency was higher than other anchors tested.

9.1.3.5 Screw

Like an embedded anchor, a screw anchor can be used to permanently moor structures. As illustrated in exhibit 9-15, a screw anchor is twisted into the sediments (similar to a screw device used to tie up dogs or livestock). Direct access to the seabed (such as with divers or underwater vehicles) is required for installation.

A screw anchor offers high holding power, although it may not work well in soft mud. Screw anchors are appealing for certain soil conditions, but they would need to be tested for pullout forces from the sea floor at the selected mooring sites.

Exhibit 9-15. Screw anchor for firmer sediments (Helix Mooring Systems 2009).

9.1.3.6 Embedded Plate and Embedded Anchors

The embedded plate anchor, mentioned in section 9.1.3.2 with fluke anchors, works well in soft sediments Embedding the plate essentially is like placing the fluke of a fluke anchor into the sediment so there is a pull perpendicular to the plate. A commercial form of this anchor, the SEPLA (Suction Emplaced PLAte anchor), appears in exhibit 9-16.

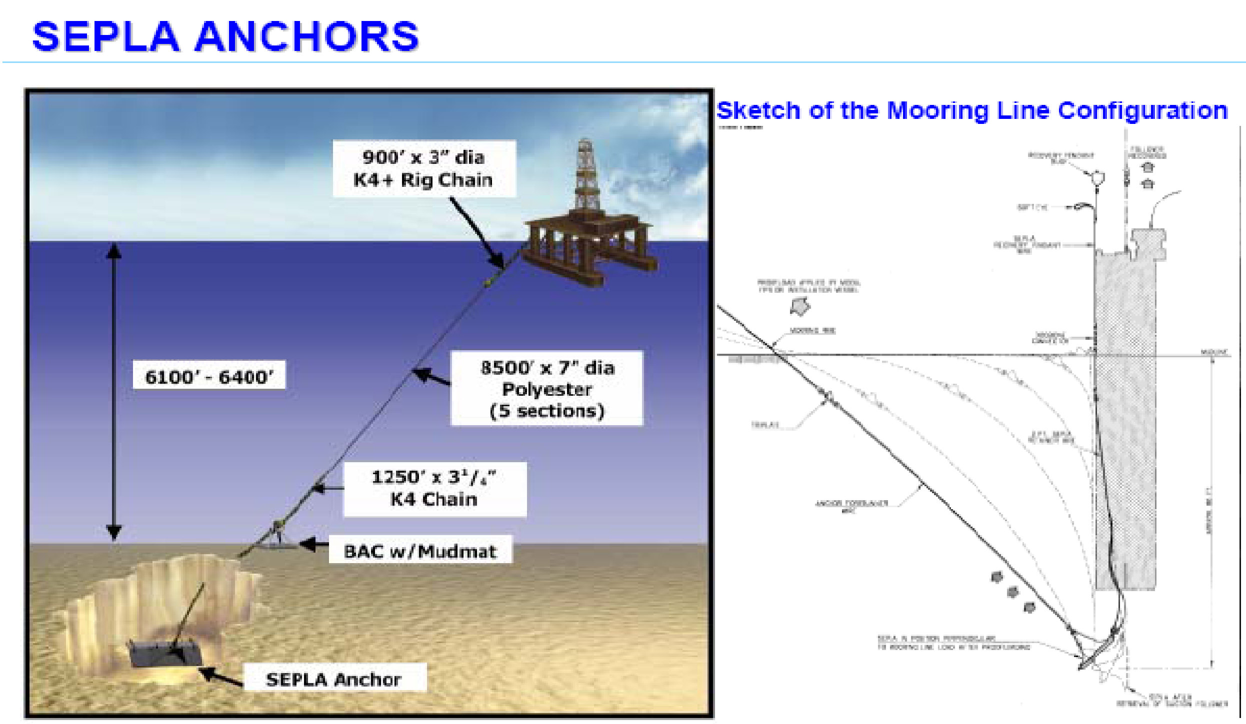


Exhibit 9-16. SEPLA embedded anchor (Liu 2004).

When appropriate rock outcroppings are available, it might be possible to embed an anchor by drilling or pounding it in place. Direct access to the sea floor is required, however, as with a screw anchor. Properly installed, embedded anchors can achieve great holding power.

9.1.3.7 Suction

A suction anchor, often used in larger offshore structure, takes advantage of the holding power of something buried deeply in the sediments. Resembling a large tube sealed at the top, the suction anchor is lowered to the sea floor, where it embeds itself some distance in the sediment by its weight. (See exhibits 9-17 and 9-18.) Then the water above the sediment inside the closed tube is pumped out, sucking the tube further into the sediments. To pull the suction mooring out, a force must be applied that exceeds the weight of sediments in the tube and the friction of the tube with the surrounding sediments – a very strong anchor of reasonable deployment weight.

Exhibit 9-17. Suction anchors being deployed (Delmar 2009b).

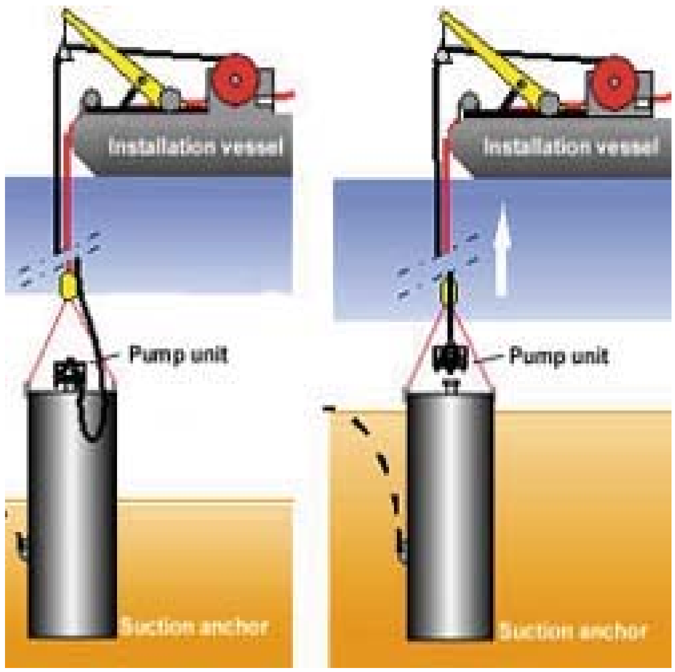


Exhibit 9-18. Schematic of suction anchors during deployment (Frank Mohn 2009).

Suction anchors are considerably more expensive than more recent developments, like the SEPLA anchor (see 9.1.3.6) with nearly the same holding strength. The pull on these anchors can be largely upward, where the fluke type can be more easily broken out of the sediments by a nearly vertical pull. They are also subjected to sideway pulls, and are used to anchor oil-rigs. The suction anchors are good in softer sediments and sands without rocks or gravel layers.

9.1.4 Mooring Lines

The mooring line is the critical component between the anchor and the platform. While chain and wire rope have been successfully used in the past, synthetic ropes now provide stronger, lower cost, and longer life solutions for many mooring applications.

Pertinent information on mooring lines, wire ropes, electro-mechanical cables and electro-optical-mechanical (EOM) cables and connecting hardware can be found in the *Handbook of Oceanographic Winch, Wire, and Cable Technology* (Bash 1991). Many of the chapters in this book contain pertinent information on buoy moorings:

Chapter 1, "3x19 Oceanographic Wire Rope," W.A. Lucht
Chapter 2, "Oceanographic Electromechanical Cables," Albert G. Berian
Chapter 3, "High-Strength Synthetic Fiber Ropes," Simeon Whitehill
Chapter 4, "Fiber Optic Telemetry in Ocean Cable Systems," George Wilkins
Chapter 5, "Rope and Cable Terminations," Robert Shaw
Chapter 8, "Operational Characteristics of Ropes and Cables," Phil T. Gibson
Chapter 9, "Equipment Lowering Mechanics," Henri O. Berteaux
Chapter 12, "Useful Information," Alan H. Driscoll[44]

While some of the information requires minor updating, the chapters contain a wealth of useful data with which to get acquainted with the mooring rope and mooring cable aspects of the highly specialized area of buoy technology. The data are usually directly applicable to wave-energy harvesting floating platforms and their moorings.

9.1.4.1 Chain

Chain has been used for anchoring vessels, buoys, and structures for many years, and the technology and regulation/inspection is well understood for larger chains. The standard chain for large structures is a stud-link chain, which has a brace through the middle of each link to strengthen the chain by preventing it from collapsing or from being weakened under the high loads required for large underwater or surface moorings. (See exhibit 9-19.) Chain often is used in large ship anchoring systems.

The large mass of the chain allows it to be dragged around on the bottom and suffer moderate corrosion and loss of material without losing most of its strength. In single-point moorings, more chain must be allowed for the drag on the bottom. In regions with consistently high swells (such as the West Coast of the United States), larger chain is required than in relatively sheltered sites (such as U.S. East Coast). In large oil rig moorings, where the chain is tight from the anchor to the structure, cathodic protection works well.

Chains are also used to moor structures, such as Washington state's floating bridges, and cathodic protection is successfully used in these cases as well. Inspection devices are being developed and introduced that climb down the chain, link by link, to assess for cracks and weakness using several instrumentation methods.

Chain is a robust, well understood, and regulated technology

Exhibit 9-19. Moderate-size stud-link chain being recovered by a fishing vessel.[45]

[44] Includes information on wire rope; electromechanical cables; fiber ropes from nylon, polyester, polypropylene and copolymers; and chain and marine hardware.

9.1.4.2 Steel Cables

Used in all sizes of moorings for many years, steel cables serve as a strong, tough member. Because steel cables weigh less than chain, their use results in lighter and cheaper moorings and allows moored structures to be lighter in weight. Nevertheless, steel cables are now being phased out in favor of synthetic ropes, which do not corrode, are as strong as steel, are lighter in weight, cost less, and have a longer life.

Some steel cables in moorings have a plastic protective jacket extruded over the cable to provide some protection against the corrosive effects of salt water. Some of these jackets have a triangular cross section applied in a spiral to prevent cable "strumming," which may weaken a cable (especially at the terminations) and can attract fish and fishbite.

9.1.4.3 Synthetic Ropes

9.1.4.3.1 Industrial Fibers Suitable for Mooring Ropes

Synthetic fibers suitable for manufacture into ropes came onto the market 40-50 years ago – nylon (polyamide), polyester (polyethylene terephthaleate), and polypropylene. These fibers made possible the production of stronger ropes than Manila fiber ropes, with a choice of working stretch.[46] Since the 1990s, copolymer fibers, which improve the strength and abrasion resistance of polypropylene fibers, have been introduced.[47]

Designated as "industrial fibers" by the Cordage Institute, this group of fibers have medium strength and a larger working stretch than "high-tenacity fibers" or "high-performance fibers," which have at least twice the strength but much less elongation.

The fairly small difference in the working stretch ranges of the different fibers results in larger differences in the stretch range of rope made from these fibers. The fiber stretch is amplified in the rope structure since the fibers are undergoing a number of spiraling processes: Fibers are twisted into rope yarns, yarns into rope twines or multi-plies, rope twines or multi-plies into larger rope strands, and rope strands into the finished rope. Each new sub-assembly stretches more than the elements composing it due to the twisting, stranding, and twisting or braiding process to complete the finished rope; concurrently, it loses some of its strength due to the arrangement in the rope.

Exhibit 9-20 lists typical properties of these fibers.

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[45] Photograph by James Irish, 2000.

[46] Manila ropes were made from the leaf stem fibers of a banana-type plant grown on large plantations in the Philippines. Manila was the only widely available fiber compatible with exposure to seawater.

[47] Copolymer fibers are a melt combination of olefin polymers (polyethylene and polypropylene) and other polymers, in particular polyester.

Exhibit 9-20. Selected properties of industrial synthetic fibers for manufacturing synthetic fiber ropes.[48]

Fiber Name	Specific Gravity	Weight in Seawater (% of dry wt)	Melting Point (deg C)	Fiber Tenacity[49] (grams/denier)	Fiber Stress at Break (1000 psi)	Working Elongation Range (%)	Elongation at Break (%)
Nylon 6 Nylon 6.6	1.14	10	218	7.5 – 10.5	109-153	1-12	16-28
Polyester	1.38	25	250-266	7.0 – 10.0	123-177	1-5	13-15
Polypropylene	0.91	-13 (buoyant)	160-175	6.5	75	1-10	18-22
Copolymers							
Polypropylene -polyethylene	0.93	-11 (buoyant)	140	7.5	89	1-7	14-18
Polypropylene -polyester	0.99	-4 (buoyant)	196	7.0	89	1-4	12-16

9.1.4.3.2 High-Tenacity or High-Performance Fibers Suitable for Mooring Ropes

In 1970, DuPont introduced the first high-performance fiber, "Fiber B," renamed Kevlar®. Exhibiting very high strength (about twice the stress at break than nylon or polyester fibers), Kevlar is available in a number of grades. For moorings the high-stretching Kevlar 29 is used.

"Aramid" is the generic name for the Kevlar fiber. Competing aramid fibers are produced in the Netherlands under the trade name Twaron by Teijin, which also manufactures the trade name Technora in Japan. Aramid fibers have a tendency to form kink-bends, which are like sharp folds of its very tiny fibers. These folds become weak spots and have up to 80 % loss of their strength (Riewald 1986).

9.1.4.3.3 Mooring Line Constructions for Buoy Mooring Ropes from Industrial Synthetic Fibers

Eight-strand plaited ropes and 12-strand braided ropes are common mooring-rope constructions from copolymer fibers. These constructions are recommended since they are torque-free (normal twisted ropes are not), they can be readily spliced in new and used condition, and they allow repairs and replacement of worn-out sections at sea. Industrial synthetic fibers are made from nylon, polyester, and polypropylene.

Double-braided ropes made from nylon and polyester fibers are also used as mooring rope candidates. Although torque-free, stronger, and easier to splice than twisted ropes when new, these ropes are more difficult to splice when used.

Even though they offer much lower self-abrasion and longer service life than other synthetic fiber ropes, polyester ropes are not frequently used for single-point buoy moorings because of their heavier weight and lower working elongation. They are, however, the only fiber rope used in special constructions of up

[48] Free Flow Energy, 2009.

[49] Because of the difficulty measuring the diameter of bundles of very fine fibers, in the textile industry the stress at break is expressed as the breaking load in weight per unit length. The result – called *tenacity* – has the dimension of a length of 9,000 meters of the fiber. This is also called the *breaking length* of a fiber bundle or rope, that is, the length of the fiber bundle or rope that has the same weight as its breaking length (e.g., consider a long length of fiber or rope suspended from a buoy or a helicopter). The tenacity or breaking length is expressed in grams/denier, with 1 gram/denier approximately 20,000 pounds/square inch, depending on the density of the fiber. Correlation: Tenacity in grams/denier multiplied by nine equals the breaking length in kilometers (e.g., a nylon fiber bundle with 9 grams/denier tenacity equals a breaking length of 81 kilometer or 50.3 miles). The breaking length of fiber rope is only about one third of the fiber's breaking length due to the many twisting processes during rope manufacturing that increase the lengths of the fibers in a unit length of rope.

to 7 inches in diameter to moor large oil-rigs in deep water in spread moorings, offering 20 to 100 years of life expectancy in these applications.

9.1.4.3.4 Stretch Hoses Alternative to Fiber Rope Moorings

High-stretch rubber hoses, connecting a surface buoy to the rest of a single-point mooring, dramatically reduce the dynamic stretching and contracting of the mooring under wave heave and eliminate the often severe shock loading of the surface buoy and its instrumentation due to sudden pickup and acceleration (in particular of chain catenary moorings during a rapid ascent of the surface buoy). Offering a proven life expectancy of at least two years, these hoses also allow the inclusion of electrical conductors and optical fibers.

The high-stretch rubber hose technology was developed at the Woods Hole Oceanographic Institution (WHOI), in conjunction with the University of New Hampshire and the Monterey Bay Aquarium Research Institute. Although the hoses perform well in research applications, additional research and development is required for the high-stretch hoses to carry the power required by the hydrokinetic power generating devices.

9.1.4.3.5 Mooring Configurations for Buoys without Shore Cable Connection

For wave harvesters designed solely to supplement the buoy's solar-panel-charged battery power, the well established shallower-water chain catenary mooring and the deeper-water S-tether mooring configurations are used, as outlined by Berteaux (Berteaux 1976 and 1991). The life expectancy of these two mooring configurations is limited to about 1 year, with exchange the most wearing mooring sections up to two years:

- In chain catenary moorings, the destructive wear of the chain in the touch-down span with the sea floor limits the mooring life.

- In S-tether moorings, the wear and tear of the upper nylon rope portion shortens the mooring life. Also the interface to the lower buoyant polypropylene rope section wears out quickly if not properly protected. The endless stretch and retraction of the upper nylon rope due to the wave motions[50] of the surface buoy causes inter-strand abrasion (wet nylon fiber has only fair inter-strand abrasion[51]). Note that only nylon fibers with an approved marine overlay finish should be used to procure nylon mooring ropes, otherwise the life expectancy of these ropes is even further compromised. The applicable procurement specifications for buoy mooring ropes are issued by the Cordage Institute.[52]

In many areas of the deep ocean, mooring lines risk destructive fish-bite attacks (Berteaux and Prindle 1987). This risk may require the inclusion of a wire rope or protected fiber rope section under the buoy, 1000 to 2000 meters long. (Kevlar jackets have been used on some ropes to protect against fish bite.) In some configurations, fiber ropes are more susceptible to cutting and abrasion – such as by the sharp edge of an anchor fluke (see exhibit 9-21) – which can be problematic. A rusty fishing trawl rubbing against the cable also can cause premature wear and lead to failure.

[50] Example: At 7 second wave period, about six million heave cycles stress the mooring during a one-year deployment.
[51] Nylon fibers should and nylon ropes should only be procured with an abrasion reducing overlay finish (Sea-Guard or equivalent), see the CI 2009-N, Guideline: Performance Requirements for Marine Grade Nylon Fiber Rope; CI-2010, Guideline: Coatings for Rope and Fiber. Available from Cordage Institute, Wayne, PA; Web-Site : www.ropecord.com. .
[52] Cordage Institute, Wayne, Pennsylvania: www.ropecord.com.

Exhibit 9-21. A polysteel rope half cut (left part of rope) by the sharp edge of the anchor fluke in exhibit 9-12.[53]

9.1.5 Anchoring and Mooring Considerations

9.1.5.1 Anchor Holding Power

For most anchors, the efficiency often depends entirely on the sea floor conditions. Anchors hold differently in clay, soft sand, hard sand, mud, and rock. In particular, sand and mud can change their properties depending on the hydrostatic pressure, which increases with increasing water depth. The holding power also depends on the sea floor topography: An anchor may hold differently in flat horizontal bottom than on the site of a sloping seamount.

The direction of pull of the mooring also is important. While for multi-leg moorings the conditions are somewhat easier since the direction of the mooring pull does not change, in single-point moorings the direction of the horizontal mooring load component is not fixed. Any fluke-type anchor can easily break out if the mooring line pull direction suddenly changes, such as under changing current and wind load.

Many experiments have been conducted to determine the holding power of different anchor types for buoy and platform moorings, and the results are as different as the soil and environmental conditions. For smaller buoys and platforms using a single-point mooring, a deadweight steel or stone anchor is the simplest solution; as noted, the safe holding power of a deadweight anchor is typically 45-50 % of its wet weight (see 9.1.3.1).

Assessing holding power – and thus the applicability of an anchor – depends on several factors:

- A deadweight anchor just has the weight to resist tension on the mooring line. With time, a deadweight anchor can become embedded in the sediment and its holding power significantly increased.
- Fluke, mushroom, and embedded plate anchors rely on embedding themselves in the sediment and using the structural integrity of the sea floor for their holding power. Consequently, the

[53] Photograph by James Iris, 2000.

geotechnical properties of the sea floor must be properly evaluated to design a successful anchoring system.

- The angle of mooring tension impacts the actual holding power. A fluke anchor, for example, can be released from the sea floor by pulling directly upward on the anchor shank. Some fluke anchors have an eye above the fluke to aid in the recovery of the anchors (see the welded loop in exhibit 9-12). To keep the tension on the anchor line parallel to the sea floor (for maximum holding power), other components may need to be added to the mooring system, such as a length of heavy chain as the bottom section of the anchor-to-mooring connection. In addition, a weight sometimes is deployed on the chain to keep it on the bottom and thus keep the pull on the anchor parallel with the bottom for maximum holding power.
- The number of anchors and the geometry of the pull on an anchoring system are critical. A platform held in position by groups of anchors off four corners, for instance, will not turn as an observation buoy will on a single-point mooring. Also, with a single-point mooring, care must be taken to put swivels in the mooring to allow the mooring chain/cable/rope to remain untwisted and weakened. In addition, an array of single-point surface platform moorings requires room to swing without becoming entangled.
- A taut three- or four-leg mooring has relatively little motion in the mooring components, and the components remain in contact with each other and have lower wear and longer life than with a single-point chain catenary mooring, which can become nearly slack and can wear more often. Also, the wear of components on the bottom becomes critical in a non-taut mooring.

9.1.5.2 Compliance

The structure –especially a surface structure (such as a floating wave or current energy conversion device) – must be able to move with the waves and currents, within the constraints of the structure use. For example, a structure needs to move up and down with the tides (generally a meter or two) and move somewhat in large, storm-driven currents. Therefore, the mooring must be designed to allow this movement of the structure due to various environmental forcing, while keeping the structure in the required position. Fighting these forces by making the mooring taut with little compliance will require large and expensive mooring components to survive the high tensions due to the environmental forcing.

A surface structure also needs to respond to the wave field. If the structure is a barge or buoy shape, then the forces are often high and the motion large. If the structure is a long cylinder, such as a spar buoy or similar to oil rigs, which are designed to have minimum vertical motion with the waves, then the compliance requirements are smaller. Subsurface moored structures must also have compliance in the mooring to allow then to move with the waves and currents, but the forces are greatly reduced the farther the system is moored underwater. Because structures and moorings move with the waves and currents, however, proper design must be made to account for these forces, and proper inspection of the mooring components must be made at regular intervals to assure that the structure is safely moored in position.

Compliance is often supplied by a chain catenary, where an extra length of chain sitting on the bottom is lifted up and down with the motion of the structure. This allows the structure to move with the waves and currents, yet supplies a restoring force to return it to the desired position after a storm has passed. Newer methods using large ropes have proved successful to supplying compliance on oil rigs. Long lengths of nylon line have been used in deep oceanographic moorings to provide a taut, compliant mooring. Modern fibers are proving nearly as strong as steel cables and are able to survive in the ocean environment for long periods of time (see 9.1.4.3). The stretch in these synthetic cables supplies the compliance, so the mooring doesn't need the extra "real estate" on the bottom required by chain moorings.

As mentioned above, new technologies, such as the stretch hose with fiber strength members and embedded conductors and optical fibers, have proven their applicability in oceanographic research and observatory moorings because they supply the required compliance, have the strength to moor the buoy platform, and provide a power and signal link across the compliant hose. These technologies have the most potential for Outer Continental Shelf depth alternate energy moorings.

9.1.5.3 Environmental Factors

The environmental conditions at a planned mooring site – wind, currents, and sea state – are needed as input to determine the semi-static and dynamic mooring forces of a planned moored surface float installation. For specific locations (usually near the coast), National Oceanic and Atmospheric Administration (NOAA) weather buoys provide sufficient time records of the environmental conditions. Average and maximum observed ocean currents and wind forces are needed for a static analysis of mooring forces, while the sea state records provide the input for dynamic analysis, both at "average" and survival storm conditions. A mooring design needs to accommodate the various environmental forces on the structure, including:

- Wind forces on the portions of the structure extending above the water.
- Wave forces on the portions of the structures and moorings at the surface of the water and extending below the surface to the depth of wave activity.
- Ocean currents on the underwater components of the structure and mooring.
- Earthquakes, which can alter the geotechnical properties of the bottom (liquefaction of sediments) and thus affect anchor holding power.
- Seabed material and its effect on holding power with different anchors.
- Biofouling, which could create microclimates around the structure and its mooring that may cause additional corrosion or detrimental chemical action. (Biofouling also increases the drag on the mooring, and this must be considered in the design.)

A site survey must include knowledge of the average, high, and highest winds, waves, and currents that impart forces on the structure to move it, data that must be considered for compliance as well as the bottom type and anchor-holding potential.

9.1.5.4 Time-Domain Modeling

The well established Woods Hole Oceanographic Institution's WHOIcable (a non-linear time domain hydrodynamic modeling program – Gobat and Grosenbaugh 2000) is widely used to determine the mooring forces under regular and "doomsday" storm wave and current conditions at a site with the proposed mooring configuration and the mechanical properties of the mooring components as input. These force predictions guide the design and selection of mooring components with a sufficient factor of safety to support the worst storm-generated mooring forces and with sufficient overall stretch to accommodate the highest predicted storm waves and storm driven ocean currents at a site.

Oil rig contractors such as Delmar have their own mooring programs, which have proven successful and are validated for these large structures but may not be applicable to smaller, subsurface moorings (particularly if they are of new technology construction). Other programs, such as the University of New Hampshire AquaFE finite element model (Tsukrov 2002) can be used for multiple leg moorings (such as exhibit 9.5) under wave and current forcing.

9.1.6 Anchoring and Mooring Electrical Power Transmission Issues

A main difference between the moorings discussed above and moored structures for alternate power is the need to transmit the electrical power generated at the structure down the mooring and along the bottom to shore, where it can be connected to the electrical grid.

9.1.6.1 Subsea Cable

The cable that lies along the seafloor from the mooring to shore is fairly well understood. As discussed in chapter 7, this cable is used in power lines underwater from shore to offshore islands. For offshore marine energy, most of these cables will be drilled through the beach region and buried under the sediments out to the power generation site.

9.1.6.2 Shallow-Water Moorings

For shallow-water moorings (30-100 meter water depth) the high-stretch taut mooring hose seems to be the best option for a survivable taut mooring. WHOI now has 15 whale moorings that have been deployed for 15 months and are being redeployed for the same time period. Over 50 stretch-mooring hoses were procured in 2007 and 2008 and most have been deployed to listen for whales.

The risky external conductor path used for the UNH Open OceanAquaculture Feed-Mooring Hose has been eliminated. This mooring was the first to incorporate electrical cables into a stretch hose for mooring a feed buoy in a specific location. This buoy used solar and wind to power the buoy's pumps and relays controlling computer and telemetry systems. The conductors are now guided into a special chamber in the hose coupling and are no longer exiting from the hose wall. Over the entire hose length the conductors are protected by layers of Kevlar tire-cord, as fishbite protection, which is turn is covered with rubber. This technology has the best potential for further development to support the offshore power industry.

9.1.6.3 Deep-Water Moorings

For deep-water buoy moorings, the EOM cable (Grosenbaugh et al. 2006), with a nylon rope strength member, performed well for 13 months in 10,000 feet (3,000 meters) of water and showed almost no sign of damage. (The fishbite jacket on the upper 1000 meters withstood several bite attacks.) The cable was deployed with a 1.05 scope and had a 500 meter buoyant jacket at its bottom end, plus some glass-balls near the acoustic release to prevent any sea-floor abrasion.

The difference between using 10,000 foot (3,000 meter) nylon rope and a slightly longer length of equally strong polyester rope is 1,000 pounds versus 3,000 pounds of rope weight suspended from the surface buoy. Alternatively one could use a sufficiently long high-stretch hose to provide the needed wave-heave absorbing stretch and to provide the additional mooring length required to accommodate the lateral excursion of the buoy and mooring under currents.

9.2 Anchoring and Mooring Inspection and Monitoring

The design, construction, deployment, servicing, and inspection of large wave-harvesting and current-harvesting energy platforms appear to be well covered in sufficient depth by the guidelines and practices developed by the oil-industry for their drilling and production platforms. The American Petroleum Institute safety and Environmental Management program for offshore operations and facilities, for instance, addresses safety management that can be adopted for the offshore power industry.

Nevertheless, it is not clear how these inspection and regulations will accommodate the wide variety of wave and current energy conversion systems that have been proposed. A large number of smaller systems in large horizontal moorings will require the development and implementation of modified and new inspection and monitoring procedures. Wave-harvesting buoys require a reliable electro-mechanical mooring link to anchors at the sea floor. Preferably this should be a taut mooring link with a hardwired conductor link to avoid the highly abrasive contact between mooring link and sea floor. Ideally the mooring should react like a pre-stretched bungee cord, which can retract its length enough to maintain a taut mooring when the surface buoy is in the trough of a storm wave at low tide, and which also has sufficient additional working stretch when the buoy is riding the top of the highest storm waves at high tide and horizontal displacement from ocean currents. This latter technology is new and will require inspection and monitoring regulations to be developed as the technology develops.

9.2.1 Best Practices and Protocols

A number of best practices and protocols will help inform the emerging offshore wave and current industry:

- It is clear from problems in the oil industry that the inspection, testing and product guarantees of each component in an anchor and mooring system will need to be carried out as in the oil industry. The size of the components may be smaller in the offshore power industry, but safe manufacturing standards must be adhered to and followed to ensure reliable components.
- Environmental studies of the geotechnical properties of the sediments at the proposed site will provide information on the type of anchor best suited for the site. Environmental studies of the wave, current, and weather forcing of any surface or subsurface structure will provide information on the buoyancy, size of mooring components, and anchors required to reliably position the structure.
- Static and dynamic models are used in the oceanographic and oil industry to promote the design of mooring systems with adequate safety. These techniques will be required for the offshore power industry as well.
- A large body of information exists within the ocean engineering community on how to stage, deploy, and work with most any size structure and mooring in almost any part of the ocean. This technology will provide valuable service to the offshore power industry.

Applicable fiber rope specifications are available from the Cordage Institute[54]:

- CI-1303, “Standard: Nylon (Polyamide) Fiber Rope, 3-and 8-Strand Constructions”
- CI-1310, “Standard: Nylon (Polyamide) Fiber Rope, High Performance Double Braided Construction”
- CI 1312, “Standard: Single Braided Nylon (Polyamide) Fiber Rope, 12-Strand Construction”
- CI-1301, “Standard: Polypropylene Fiber rope, 3 and 8-Strand Constructions”
- CI-1401, “Cordage Institute International Guidelines: Safer use of Fiber Rope.”

9.2.2 Recommended Inspection Methodologies

Because power transmitted from the generating structure must be transferred to subsea cables, we recommend attention to the following concerns, which do not appear to be covered by existing regulations, safeguards, and design standards:

[54] Cordage Institute, Wayne, Pennsylvania: www.ropecord.com.

- The attachment point between the underwater cable-to-shore and the mooring presents a challenge. The two components must be deployed as separate pieces and then plugged together. Several high-voltage, high-current underwater connectors that can be mated by remote underwater vehicles (ROVs) are available, however these components need to be evaluated and a methodology of safe use developed. Much of this technology can be borrowed from the offshore oil industry, but it should be modified by the power-carrying requirements of the cables and connectors.
- The movement of the mooring line and possibly the anchor must be taken into consideration. Any movement of mooring components in the waves and currents creates the potential for wear and premature failure at the point of relative movement.
- Catenary moorings do not work with electrical cables running from the buoy to the sea floor due to the impossibility of avoiding abrasion with the sea floor (to which copper conductors would be even more susceptible to failure). The mooring needs to be a taut mooring to minimize any conductor trauma between mooring and cable to shore.
- The taut-moored structure (tension-leg) has additional constraints. The rope in the mooring supplies some stretch (unless it is a tendon tension-leg). Electrical conductors don’t stretch, but designs have been made using conductors coiled around specially constructed hoses to allow the whole assembly to stretch without relative movement or failure. This technology needs further development and testing before it can become a viable tool for offshore power systems, but it appears to have the best potential at the present time.
- A loose electrical cable moving with the currents and waves will be subject to early failure. Also, the junction at the structure needs to be designed properly with a strain-relieving boot or other component to reduce the bending moment between the structure and cable. Inspection of both the design and the installation to minimize any relative movement will be critical to the safety and survival of these power generating systems.
- The failure of the high-voltage conductor can pose a significant safety hazard as well as cause potential danger to aquatic life. Proper design, testing and construction of the systems will require inspection and new regulations to cover the considerations listed.
- Safety shutdown needs to be designed into the power transmission network to prevent accidents harmful to human, marine life, and other components in the power generating network.
- Periodic servicing of the power generating components (due to corrosion, biofouling and wear issues) presents an optimum time to recover and inspect mooring components *on shipboard*.
- Standard mooring inspection techniques used on oil platforms would work well on moored offshore power generating moorings. ROV inspection of mooring lines, bottom chains, anchor attachment points, and power cables would be optimum. Experience in the oceanographic research field implies that every other year may be appropriate for the largest inspection interval, but probably 6 months is more desirable until experience is gained.
- In-situ monitoring of the systems is a must. The mooring and electrical conducting cable system can have a ground fault detector installed that will shut down the system if any leakage of current is detected between seawater and any circuit or isolated component. This will prevent serious electrically driven corrosion, potential shock safety issues, and harm to marine life.
- Also, in-situ monitoring of the flotation, power generating equipment for salt water intrusion is simple and can provide advance warning of catastrophic failure and potential safely issues.

Chapter 10. Operations Management

10.1 State of Operations Management in Industry

Most organizations working on hydrokinetics are still mainly focused on equipment research and development, and they presently do not yet have fully developed operations management systems for energy production. Many of the hydrokinetic companies do not have plans for offshore deployment and are focused more on near-shore and tidal areas. Therefore, in order to describe fully deployed offshore wave and current energy production, certain assumptions and a degree of vision are required:

- Energy prices will rebound to make offshore renewable energy developments economically viable.
- Marine renewable energy production in the United States will be more likely where the electricity rates are highest and there is a deregulated power market structure.[55]
- A supportive regulatory environment for marine renewable energy will emerge.

Given these assumptions, we project that offshore wave and current energy production will mainly be unmanned, be remotely monitored, utilize alternative and combined production operations, and be operated from either a shore-based facility or an existing platform within a limited range from the deployed array.

10.1.1 Remotely Monitored Operations

It is projected that the majority of wave and current installations will be unmanned and remotely monitored and operated from either a shore-based facility or an existing platform within a limited range from the deployed array.

10.1.2 Alternative-Production Operations

According to the prevailing mindset, wave and current energy devices are going to produce electricity for a local, regional, and/or national electrical grid. Although this application is likely, there may also be applications of wave and current devices for other applications, such as freshwater generation. Therefore, any regulatory framework that guides an installation and subsequent operation has to be robust enough to account for a variety of applications (CETO 2009).

10.1.3 Combined-Production Operations

Aside from the technological complexity of offshore renewable energy production, one of the main barriers is the cost of installing subsea transmission cabling. Economic viability for an installation will be a tradeoff between its power generation capacity and installation costs and complexity: The more complex and costly the system, the more energy it will have to convert and deliver to be cost effective. Some of the methods in the planning stages to achieve economic viability in the face of high installation costs are to combine wave and current facilities with offshore wind facilities or with natural gas fired power plants (GHOEC 2009). Having a natural gas plant, for instance, would significantly change the operational requirements; the facility would then be a manned facility and additional safety requirements would be introduced.

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[55] Conversation with William P. Short, former executive of Ridgewood Power Management.

Some of the major oil companies have also invested in this technology. It is not thought that wave and current energy is going to be used for primary power generation for offshore oil and gas production. However, there are some companies that intend to deploy wave and current devices adjacent to existing oil and gas production and use these devices as auxiliary power generation (Wavebob 2009).

10.2 Operations Management Inspection and Monitoring

10.2.1 Regulatory Structure for Operations Afloat

The existing regulatory environment covering operations management is derived from the existing offshore marine industry and the coastal and deepwater maritime industry. Operations management of offshore marine renewable energy production will have to operate in both environs. A good portion of the operations will be maintenance and servicing, which will likely be accomplished from vessels that will be both inspected and uninspected. Therefore, depending on the situation and location, the U.S. Coast Guard (USCG) will likely be the lead agency in overseeing these operations. Also, the USCG regulates commercial diving operations, which will be an important part of inspections, maintenance, and repair of wave and current energy conversion devices.

If marine operations on the wave and current energy conversion facilities is being conducted from USCG-inspected vessels, the following international rules and conventions will be in effect for operations management:

- 46 CFR - Shipping
- 46 USC 30104 – U.S. Jones Act
- COLREG – Convention on the International Regulations Preventing Collisions at Sea, 1972
- MARPOL 73/78 – International Convention of Maritime Pollution Prevention
- NPDES – National Pollution Discharge Elimination System
- Oil Pollution Act
- SOLAS – International Convention on the Safety of Life at Sea
- STCW- International Convention on Standards and Training, Certification, and Watchkeeping for Seafarers, 1995

Under the SOLAS International Convention, shipping companies have had to have a safety management system in place since 1997. To comply with this requirement, many organizations that are engaged in the conventional maritime industry have Safety, Quality, Environmental Management Systems (SQEMS) in place that are designed and audited to International Organization for Standardization (ISO) 9001 2000 and ISO 14001 2004 Standards. ISO 9001 2000 is a generic model for quality management systems, ISO 14001 2004 covers environmental management systems, and a more recent standard, ISO 18001 2007, covers health and safety management systems.

10.2.2 Regulatory Structure for OCS Facility Operations

The present regulatory structure for fixed offshore wave and current energy operations is obviously less defined. Compliance with existing environmental regulations is expressed as an overwhelming concern by many of the stakeholders in the marine renewable energy area. Most relevant environmental regulations have been listed, however, the focus of this report is on the engineering and safety aspects of offshore marine renewable energy. Environmental regulations applying to marine renewable energy development include:

- 30 CFR Parts 250, 285, and 290 – Proposed Ruling
- Clean Air Act
- Coastal Zone Management Act
- Endangered Species Act
- Federal Water Pollution Control Act (Clean Water Act)
- Fisheries Conservation and Management Act
- Marine Mammal Protection Act
- National Environmental Policy Act
- National Historic Preservation Act
- National Pollution Discharge Elimination System
- Oil Pollution Act
- Port and Waterways Safety Act

10.2.3 Occupational Health and Safety Regulations

The proposed ruling 30 CFR Parts 250, 285, and 290, "Alternative Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf," appears to draw heavily on the existing regulations for conventional oil, gas, and mineral operations for the Outer Continental Shelf (OCS). In regard to safety, in Subchapter H, Mineral Management Service (MMS) states that it intends to use "adaptive management practices." Based on the novel and uncertain nature of this industry, a flexible regulatory attitude will be an absolute necessity.[56]

The regulatory oversight for occupational health and safety on the OCS initially rested with the Department of Labor's Office of Occupational Safety and Health (OSH). However, in 1979, a Memorandum of Understanding (MOU) was drawn between OSH and the USCG. Under this agreement, the USCG assumed the responsibilities for occupational safety and health on the Outer Continental Shelf. The existing MOU and subsequent Memorandum of Agreements between MMS and the USCG assist in defining USCG responsibilities and authorities. Specifically, the 2004 MOU between MMS and the USCG addresses overlapping jurisdictions. As per this MOU, "the USCG is responsible for promoting workplace safety and health by enforcing requirements related to personnel, workplace activities, and conditions and equipment on the OCS."

It is important to note that the USCG derives its authority to regulate health and safety on the OCS from its MOU with the OSH. Two directives define the relationship between the USCG and OSH:

- OSHA/U.S. Coast Guard Authority of Vessels – OSHA Directive CPL 02-01-020 (1996 November 8) (OSHA 2009)
- Memorandum of Understanding Between the Occupational Safety and Health Administration and the U.S. Coast Guard. OSHA Directive CPL 02-00-046 (1982 January 20) (MMS and USCG 2004)

Both directives are in the process of being revised and updated. The estimated completion date for these revisions is approximately mid-year 2010. It is not known whether or not alternative energy projects on the OCS are specifically addressed within these revisions.[57]

[56] See subchapter H of the proposed ruling.
[57] Conversations with Steve Butler from the OSHA Marine Enforcement Branch and LCDR Ullrich from the USCG Division of Offshore Compliance.

10.2.4 Best Practices

For an offshore wave or current installation, the work will likely be coordinated and administered from a shoreside facility but executed from floating platforms and service craft. Consequently, there will be significant parts of the marine operation that fall under the jurisdiction of the USCG for inspected vessels or under the Occupational Safety and Health Administration (OSHA) for uninspected vessels and shoreside facilities.

It is also recognized that some of the challenges faced by the offshore marine renewable energy industry will be the same that has been experienced in the offshore oil and gas industry, as underscored by Det Norske Veritas (DNV 2005a):

> "The environmental loads and technical challenges faced by offshore WEC devices are very similar to those experienced by offshore oil and gas installations. The solutions found for the oil and gas industry and the associated technology development have been calibrated to an internationally acceptable safety level and have an adequate track record."

The following policies, procedures, and practice have been selected as best practices in related industries. These items are considered to be necessary components of a marine renewable energy operation to ensure safety to personnel and minimize harm to the environment.

10.2.4.1 Clear, Understandable Policies with Goals and Commitment from Management

Regardless of the platforms on which offshore renewable energy operations will be conducted, the common elements of best practices will be required to ensure safe operations with minimum risk to personnel and the marine environment. The operator's safety management system should include the goals of zero incidents and total compliance and also have a strong demonstrated commitment from the company's management. Consequently, the policies that support these goals need to be clear and understandable and cover all facets of the operation. With regard to marine energy industry, these policies and procedures will require frequent revision and therefore need to be living documents. A management system is only as good as it is maintained. Because many of these operations will be done with little or no history, the policies and procedures will have to be front loaded with risk assessments and followed by frequent revisions to add clarity and definition.

The safety philosophy established to generate these policies and procedures should take into consideration the following aspects (EMEC 2009)

- Risk to life (during installation and removal, access to device during in-service life, risk to navigation and others during in-service life).
- Environmental impact due to any fluid releases, anti-fouling coatings, bilge water, and location of site relative to sensitive environments (protected species or sensitive sites and visual impacts).
- Loss of production.
- Inspection and maintenance cost, risks during removal of equipment for inspection and maintenance.
- Reputation of developer, industry, and concept (survivability of the device to extreme environment is very important in terms of reputation).
- Underwriter perception of risks and definition of premium value (during installation and removal, and in-service life).
- Financial or venture capital communities' perception of risk to the return on investment

- Expected safety level by Authorities. This may include Authority requirements in other countries which are potential marketing target for the devices.

10.2.4.2 Risk Assessment and Management

Good risk and hazard assessment and management is a best practice that will be an essential component for offshore marine renewable energy operations. The operations management of an OCS renewable energy facility should integrate risk assessment into the entire spectrum of operations, from programmatic functions to specific job tasks. Individual job hazard and safety hazard analysis should be built into the system. A record of this information should be maintained and be capable of integration with the work-permitting system. In other words, having a job hazard analysis has become a common industry practice. However, less common is the organization of this practice such that the job hazard analysis is directly referenced to other work logs and permitting systems. This type of integration is a best practice that demonstrates the operator's commitment to using and maintaining the system.

10.2.4.3 Self-Audit Programs, Active-Monitoring Systems, and Management-of-Change Processes

Successful safety systems usually are designed with internal controls that enable the people involved to actively manage the system. A safety system of this design will often have one or more of the following components:

- Self-Assessment and direct observation by co-workers
- Tracking and reporting of safety metrics
- Systematic and thorough safety equipment inspections
- Regular review of controlled procedures for required changes and improvements
- Examination of auditable documents such as work permits
- Continual Environmental Monitoring Programs such as toxicity monitoring, etc.
- Quick identification of hazards
- A active near-miss reporting system

A safety management system requires maintenance through internal audits. The practice of internal auditing has a wide variance. A best practice identified in related maritime industries is the assignment of in-house quality assurance officers who continually review policies, procedures, and permitting system compliance. A healthy safety management system will be evident by engagement of company employees at all levels. The intent of introducing quality assurance officers is not to discourage this engagement; the intent is to assist the workforce in achieving the goal of total compliance and allowing them to focus more on safety. Another benefit of having an individual assigned to quality assurance is that it promotes an active monitoring system that will facilitate rapid changes to the management system if required. These changes should be channeled through a management of change process that is organized and well documented. This type of rapid response will be required in the hydrokinetic industry due to the lack of historical knowledge and trailing metrics.

10.2.4.4 Environmental Impact Minimization Programs

Environmental sensitivity is a best practice in the maritime industries. An active program of identifying elements of the operation that impact the environment, combined with the development of mitigation strategies for those impacts, is considered an industry best practice. Common terminology within the auditing community refers to this minimization program as environmental aspects and impacts. One example of this minimization program is the operator maintaining an accurate hazardous material and substance inventory and a corresponding tracking process. Along with this process would be a documented program for minimizing the use of these products and/or substituting them with more environmentally benign products. In this particular example, it is projected most hazardous inventories will be maintained in the shoreside support facilities. Hazardous materials in the wave and current devices will primarily be operating fluids, such as hydraulic oil and lubricants.

10.2.4.5 Marine Waste Disposal

Marine waste disposal is closely related to environmental impact minimization. The current industry best practice is zero discharge. Recent legal decisions regarding the implementation of the National Pollution Discharge Elimination System (NPDES) bears direct relevance to this subject. Marine vessels were historically exempt from NPDES regulations, however, recent litigation has overturned this exemption and vessels will have to comply with this regulation in addition to the International Convention of Maritime Pollution Prevention (MARPOL) annexes. Good environmental stewardship entails minimizing the materials and processes that generate the waste streams. In the case of wave and current devices, waste disposal is projected to be mainly from any in-situ servicing of the energy conversion systems. Other potential waste streams in regard to wave and current devices may be generated from brine and effluent discharges from units with either sodium hypochlorite injection systems for marine growth control or freshwater generation systems.

10.2.4.6 Comprehensive Maintenance Systems

Most marine organizations have some form of a preventative maintenance system, yet preventative maintenance is only one aspect to reliable equipment performance. As a practice, organizations should have a comprehensive maintenance system that not only incorporates the preventative activities required but also includes condition-based maintenance based on close inspection and monitoring of equipment operation. By itself, a preventative maintenance system does not allow for the extensive variables that will be encountered in maintaining a wave and current energy development.

10.2.4.7 Work-Permitting Systems

A work-permitting system for tasks with a high potential for risk to personnel and/or the environment needs to be in place. An industry best practice is to have each work-permitting system integrated with the maintenance system and hazard analysis program. It is recommended that permits be issued for the following types of work:

- Hot Work Welding and hot work regulations applicable to wave and current devices vary depending on the application of the technology. If the devices are incorporated into an oil and gas operations, the regulation as prescribed by 30 CFR 250.109 through 250.113 could apply. However, for other operations, the general American Welding Society (AWS) standard can be applied. There will be a requirement for underwater welding that should be regulated in accordance with AWS D3.6M:1999, “Specification for Underwater Welding,” and also requirements prescribed for commercial diving operations.

- Confined-Space Entry Confined-space entry will be of particular importance for performing inspection and maintenance on unmanned wave and current equipment that will be compartmentalized for stability and flooding control. These spaces will not have forced ventilation and will be sealed. Therefore, a good confined space entry permitting system with procedures will have to be utilized to ensure atmospheres that are safe for both men and hot work.

- Lock Out – Tag Out A lock out/tag out (LOTO) system is an industry best practice that should be applied when personnel are working on any mechanical and/or electrical devices that generate, store, or distribute energy. An effective LOTO system should be simple enough to encourage its use. However, it also must include accountability, so only qualified personnel can authorize and verify that the appropriate equipment has been de-energized and safely isolated for maintenance, inspection, and/or repair. A LOTO system also must include a prescribed system for reenergizing the equipment after work. The application of this system for wave and current devices will be in many areas and could vary from hydraulic tuning circuits to navigation lighting circuits.

- High-Voltage Permitting System Medium- and high-voltage electrical equipment is becoming increasingly more common in related maritime industries in the form of dynamic positioning systems, frequency drives, and other driveline equipment. Consequently, the companies that have this type of equipment have typically developed a high-voltage policy along with a high-voltage work-permitting system. This is identified as an industry best practice because there will be a variety of trade skills required in the inspection and maintenance of wave and current devices. A clear policy of when work should be accomplished on high-voltage electrical equipment and how it should be performed are essential in maintaining safe operations. Typical threshold values when a high-voltage policy is implemented are 1000 volts alternating current (AC) and 1500 volts direct current (DC). The permitting system should be integrated with the maintenance system and hazard analysis procedure. Many of the wave and current generation systems in the planning stages will be networked into substations to minimize the amount of subsea cabling. A clear method of isolating an individual converter or section of the electrical distribution system from the rest of the network will be needed to be established.

- Diving and Subsea Operations Diving and subsea operations will introduce some of the highest risk to wave and current system operations. A good work-permitting system for these operations that is backed up by a clear and definitive policy is crucial. Part of the policy should be managing the operation to minimize the use of diving operations if possible. Some wave and current system maintenance plans will involve complete unit extraction and exchange where by most of the maintenance is performed at a shore-based facility. Other subsea operations, such as structural and bathymetric surveys may be conducted by remotely operated vehicles (ROVs). However, when no other option is available and manned diving is required, it should have a permitting system and be conducted in accordance with the USCG commercial diving standards and industry best practices.

10.2.4.8 Weather Forecasting and Environmental Monitoring

Survivability and reliability of wave and current devices on the OCS are going to be key concerns. Industry best practices to ensure survivability and reliability include accurate weather forecasting and real-time environmental monitoring. Because wave and current devices are likely to be remotely operated, a successful remote operation will require accurate monitoring equipment recording and the transmission of real-time data on such parameters as wave height, period, and direction, along with wind speed, water velocity, and other condition variables.

10.2.4.9 Communications

Having a good communications policy backed up with good communication systems is recognized as being an industry best practice in related industries. Many root cause analysis of accidents have poor communication as a contributing factor to the accident. For the wave and current energy installations, it is recommended the communication policy be well integrated into the emergency response planning.

10.2.4.10 Contractor Safety Programs

Contractor safety is being increasingly recognized as a significant source of workplace injury, and companies in related maritime industries are making efforts to improve safety performance in this area by establishing stronger policies for contractor safety. Ensuring that contractors have the appropriate training, certifications, and gear before arriving at the OCS facility is essential. Not only is it the safest method, it is the most efficient. Therefore, the implementation of a proactive contractor safety program is recognized as an industry best practice.

10.2.4.11 Evacuation and Medical Treatment Plan

Having good medical and evacuation treatment plans, combined with trained first-responder personnel, is recognized as an industry best practice. There doubtless will be some unforeseen circumstances during wave and current energy farm development. Hopefully, a combination of good planning, good policy, and prudent management will prevent any serious injuries. However, an operator needs to be prepared for the unknown and be able to respond rapidly when an accident does happen.

10.2.4.12 MMS Safety Alerts and Notice to Lessees

The existing MMS system of generating safety alerts and communicating to its leaseholders through Notice to Lessees (NTLs) should be recognized as an industry best practice. This system of communication is a clear indication of a responsible and professional regulatory body. It is recommended MMS create a similar system for wave and current energy developments or incorporate them into the existing system.

10.2.5 Recommended Inspection Methodologies

10.2.5.1 Safe Access to an OCS Facility

Access to many existing OCS facilities for the purpose of inspection and monitoring is accomplished by helicopter as mandated by 30 CFR 250.132. Wave and current developments may not be able to easily accommodate this access requirement. It is recommended that the operator and/or leaseholder be required to provide safe transportation to and from an OCS facility for MMS personnel for the purposes of inspection and monitoring. Navigation in and around these facilities may be complicated and it would not be recommended for MMS to provide its own waterborne transportation.

10.2.5.2 The Use of SCADA Systems – Supervisory Control and Data Acquisition

State-of-the-art of supervisory control and data acquisition (SCADA) systems will be required for remote operation of wave and current energy developments. Depending on the complexity of the system, the operator can capture and store a wide variety of information concerning the operation. This information can be trended and analyzed. For inspection, information could be requested that includes instantaneous power generation rates and total energy generation. The use of SCADA systems by regulators can also be effectively used to audit operations management, in addition to evaluating equipment condition and facility production. Depending on the system design, these systems can be fully capable of electronically logging all human interface with the energy generation systems.

10.2.5.3 Alternative-Compliance Programs

Many deep-sea maritime companies are enrolled in an alternative-compliance program in which the classification society assumes the inspection role for statutory requirements that historically were accomplished by the flag state authority. The American Bureau of Shipping (ABS) has been one of the classification societies that has been performing this role. The role of enforcement still rests with the USCG, however the ABS reports any violations. This alternative-compliance program does not relieve the operator of his or her obligations to report any incidents. This program decreases the amount of redundancy that sometimes exists due to inspections and surveys carried out by both the flag state authority and a classification society. In the case of wave and current energy conversion development, the classification societies are taking an active role in this industry and will most likely have the expertise in place for the industry when it is needed. It is recommended that MMS explore this type of alternative compliance arrangement for its inspection requirements.

10.2.5.4 Remotely Operated Vehicle Inspections

Remotely operated vehicle (ROV) inspections will be built into the subsea inspection and survey plans for some of the wave and current energy developments. These underwater inspections will serve as part of the condition-based maintenance and monitoring program that will reduce diving operations and maintenance requiring the removal of hardware from the water. These ROV inspections have the capability of full video feed. It is recommended that a submission and/or review process of any underwater ROV inspections be incorporated into the inspection process. Not only is this information valuable for assessing structural conditions, it can also be useful in evaluating the effectiveness of the operator’s maintenance program.

10.2.5.5 Electrical Systems Maintenance and Monitoring

The electrical systems supporting wave and current energy developments should have an inspection program built into them. Periodic maintenance of the electrical systems may include thermographic monitoring and switchgear maintenance. These inspections are usually conducted by contractors and have inspection reports associated with them. Electrical maintenance and monitoring is obviously an equipment-based inspection methodology. (Electrical maintenance and monitoring is included in the operations management section because the results of these inspections would give a regulator a gauge of how well the operator is maintaining the facility.)

10.2.5.6 Annual Operator Safety Performance Review

An annual operator safety performance review like what is conducted for MMS conventional leaseholders is a good practice and recommended. This could be combined with any other inspections to be carried out by MMS. MMS could conduct these reviews in-house or decide to outsource these reviews to a third party audit company that are experts in the field of safety management system review and can draw from international experience.

10.2.5.7 Proactive Inspection Methodologies: Pre-testing, Pre-planning

Every offshore operator has a different perspective on how to prepare themselves for external inspections. These preparations range from no preparation to proactive steps such as the development of an inspection pre-plan, accompanying pre-testing, and documentation of this pre-testing, which is presented to the inspection authority. The proactive style of inspection preparation typically results in the best inspections results and allows for the highest level of transparency between the operator and the inspection authority.

Building requirements in the inspection process for pre-testing plans and documentation in exchange for reduced inspection burdens is a good alternative to encourage this process.

10.2.5.8 Production Plans

It is recommended that the wave and/or current developer submit a production plan to MMS for their operation. However, MMS should be sensitive to the fact that the operations will be highly variable. Energy generation rates will be variable and, in addition to planned maintenance, there will also be unscheduled maintenance and repair operations. Maintenance and repair operations for grid-tied installations will also be dependent on the electrical market conditions, which may vary daily (MMS 2001b).[58]

10.2.5.9 Incident Reporting

It is recommended that the operator has an incident-reporting system in place with MMS that would be equivalent to the existing system for conventional oil and gas leaseholders that is prescribed by 30 CFR 250.187 through CFR250.191. However, there are some obvious differences that will exist in the nature of the incidents that are to be reported. The reporting requirements should apply to incidents that occur on the area covered by the lease, right-of-use and easement, and/or right-of-ways associated with any undersea transmission gear. Also, is it recommended the reporting requirements include any vessel support activity that is taking place while servicing these areas. The incidents that are recommended for notification to MMS from a wave and/or current leaseholder include, but are not limited to the following:

- Fatalities
- Injuries that require evacuation of the injured person(s) from the facility to shore.
- Lost time work injuries and recordable injuries as outlined by OSHA.
- Fires and explosions.
- Collisions and/or entanglements that result in property or equipment damage greater than $25,000.[59]
- Incidents involving structural damage to the wave and/or current installation.[60]
- Incidents that damage the aids to navigation or warning systems for marine traffic and/or other operations in the immediate vicinity of the installation.
- Incidents that damage or disable safety systems.
- Incidents involving crane or personnel/material handling operations.
- Evacuation incidents.
- Unintended flooding and/or loss of buoyancy control.
- Unintended movements of converters and/or support equipment from its deployed area.
- Releases of air and water pollutants as prescribed by the National Pollution Discharge Elimination System (NPDES) regulations.
- Incidents involving the permanent loss of communication and subsequent control of deployed gear.
- Other incidents not listed resulting in property or equipment damage greater than $25,000.

[58] Conversation with William P. Short, former executive of Ridgewood Power Management.
[59] The definitions of “collision” and “property or equipment damage” are the same as listed in 30CFR250.188.
[60] “Structural damage” in regards to the wave and current installations should mean the damage is severe enough that the equipment is inoperable or its operation is significantly degraded.

10.2.5.10 Natural Environmental Event Reporting

It is recommended that an operator participate in a damage reporting program similar to the existing program for conventional MMS leaseholders (MMS 2001a). Based on the probability of the offshore renewable energy installations being remotely monitored and operated, timely notification may be delayed until the next scheduled maintenance operations. This reporting system could also aid other agencies based on the environmental monitoring information gathered by the operator from its instrumentation.

PART IV – RESULTS

Chapter 11. Safety and Regulatory Gaps

11.1. Wave and Current Energy Conversion Device Safety and Regulatory Gaps

11.1.1. No Specific Design and Construction Standards

At present, design and construction standards developed by classification societies specifically for wave and current energy conversion do not exist. Det Norske Veritas (DNV), the Norwegian-based classification society, one of the leading authorities for establishing standards for the marine renewable technologies, and a member of the International Association of Classification Societies (IACS), introduced guidelines in 2005, *Guidelines on the Design and Operation of Wave Energy Converters*. In this publication, DNV gives guidance on existing standards used in the conventional maritime industries. The European Marine Energy Centre and International Electrotechnical Commission (IEC) Technical Committee 114 are also working on standards development. Nonetheless there are no final, comprehensive standards that are exclusive to the hydrokinetic industry.

Although industry leaders in both wave and current energy conversion are starting to emerge, the span of technologies within these areas remains quite broad. The guidance that has been developed to date is sensitive to this diversity, but, unfortunately, it also lacks needed specificity in critical areas.

The conventional standards for ships, offshore platforms, and other marine structures required decades of experience to develop, and those standards continue to evolve. The hydrokinetic industry will benefit from these related industries and standards, but it is going to take years and direct experience to develop a set of specific standards for wave and current energy conversion. In the meantime, collaborative efforts and good communication by all marine renewable energy stakeholders will be required to minimize the risks associated with installation, operation, and maintenance of the emerging wave and current energy conversion technologies.

11.1.2 Accessibility of Existing Standards

The existing relevant engineering standards that are general standards or standards from related industries are often prohibitively expensive. Consequently, the accessibility to these needed standards is limited. Accordingly, developers lack the necessary knowledge in this area and have not adequately incorporated these standards into their design process. This situation was clearly evident following Free Flow Energy's direct electronic inquiry made to industry participants.

11.1.3. Plan Approval Process and Accurate Engineering Plans

The absence of specific design and construction standards may result in some gaps in the engineering process. These gaps could lead to premature failure and quite possibly major safety issues. To avoid these problems, site developers will have to work very closely with both technology companies and regulatory agencies. A concurrent engineering process is recommended in this area.[61] A concurrent

[61] A concurrent engineering process is defined as having all the relevant parties involved in the planning and approval process from, conceptual design through final "as-built" drawings.

engineering process will educate all stakeholders throughout the development process, ultimately resulting in a project that better serves the public interest.

11.1.4. Safety-Sensitive Engineering

DNV guidelines recommend the inclusion of a suite of safety-related subsystems and considerations. The safety elements include, but are not limited to:

- Proper engineering documentation, such as one-line diagrams for emergency safety systems, including:
    - Emergency and navigation lightings
    - Fire detection, alarm, and extinguishing systems
    - Watertight doors and other electrically operated closing appliances
- Battery-operation capability for systems with a safety function
- Fault and alarm indication for safety and control systems
- Self-monitoring requirements for alarm systems
- Automatic re-start of safety critical systems
- Slowdowns and shutdowns for critical conditions

These safety elements, which were taken from the relevant standards that DNV referenced, constitute a best effort by the classification society. However, these safety considerations do not take into account features that will be specific to wave and current devices, such as safety lock-out systems for the conversion equipment or the identification of business-critical components specific to a wave or current energy converter. With numerous designs currently under development (see chapter 6), the classification societies would almost have to develop customized standards for each type of equipment. Also, primary objectives in the design of these wave and current devices are optimizing both the extraction of energy and the efficiency in which that extracted energy is converted and distributed. Integrating safety into the design will in some cases compromise the primary objectives. Based on the fact the vast majority of these conversion systems will be unmanned designs, the safety elements will be incorporated to minimal standards (DNV 2005b).

11.1.5. Equipment, Manufacturer, and Parts Certifications

For classification societies to approve designs and installations, the approval process extends back to the original manufacture of critical components. This means that component suppliers must have the material and/or components that they are supplying certified. The certification ensures that the material and/or component is built with approved materials and meets the classification society standards. Business-critical components specific to wave and current devices are not specified yet. Additionally, the manufacturers of these components in many instances are not advanced in seeking certification for their equipment.

The identification of business-critical components specific to wave and current devices will extend into operation and maintenance of the systems. Although there is no regulatory requirement, best practices in related industries typically involve an operator’s policy that only original equipment manufacturer (OEM) parts will be used in the repair and/or replacement of business-critical components.

11.1.6 A Need For Understanding the Potential of the Resource

Information on the potential of Outer Continental Shelf (OCS) ocean energy resources has not been verified, thus a wide degree of variance in the data exists. At present, regulators often must rely on information provided to them by potential developers. This lack of verifiable and impartial scientific analysis of the resource does not allow for good planning and management by regulators.

11.1.7 Adequacy of Shore-Based Infrastructure

The shore-based support required for the wave and current energy industry has not been clearly defined. A site with good energy characteristics may not be viable at present because of a lack of necessary shore-based support structure. Before significant development efforts are undertaken, these support requirements should be determined and evaluated.

11.2. Electrical Transmission and Interface Safety and Regulatory Gaps

Electric power safety requirements are well defined by many organizations with well-established histories. (As mentioned earlier, connection to the power grid largely involves satisfying the requirements of the state and local utilities, in cooperation with the U.S. Army Corps of Engineers.) Despite the history and the well-defined requirements, however, some gaps do exist, involving security, grid adequacy, and transmission costs.

11.2.1 Subsea Grid Security

During time of conflict, power transmission and grid tie-in and communications infrastructures can become primary targets. (During World War II, great efforts were made to sever subsea communications cables.) If the country becomes dependent on marine energy, offshore wave and current energy conversion installations and their subsea electrical transmission and grid interface systems could become vulnerable. It is recommended that operators submit a security plan for their development that includes security provisions for subsea cable networks.

11.2.2 Existing Grid Adequacy

The grid infrastructure in the United States needs considerable enhancements to accommodate large-scale renewable energy technologies, such as ocean energy.

11.2.3 Transmission Complexity and Costs

Subsea power transmission and grid connection is a well established industry. Perhaps the single greatest concern will involve the large-scale interconnection of device arrays at sea and the sophistication of control systems required of power conditioning such systems. WaveHub, an at-sea device-interconnection project proposed for installation ten miles off of the coast of the United Kingdom, will facilitate the interconnection of up to 20 megawatts of power from multiple devices to the UK power grid at an estimated cost of 28 million pounds.

11.2.4 Subsea Electrical Connections

A major potential problem exists in providing underwater power cabling from a surface or submerged power generator to the underwater cable that will carry the power to shore and the power grid. Effectively getting electric power from the generator to the sea floor cable requires underwater, high-power-rated connectors that can be safely handled by divers and remotely operated vehicles (ROVs) and/or autonomous underwater vehicles (AUVs). These connectors will be used to connect and disconnect the underwater power generating device from the moored structure for servicing. These connectors will also be used to connect and disconnect the moored structure/mooring cable to the seabed cable which runs to shore during deployment or recovery of the mooring. Further design advances and research is required to ensure the technology is reliable and safe..

11.3. Structural Safety and Regulatory Gap

11.3.1 Prediction Models and Industry Experience with the Use of Composites

Experience with the use of advanced composite materials in the marine environment is growing. The use of the composites in the construction of both conversion equipment and associated structures is projected to be relatively high in comparison to other conventional materials because developers are striving to minimize the unit costs of construction to make wave and current energy economically viable. Nevertheless, even though experience in this field is growing, no reliable prediction models for failures in this material based on its inherent variability exist. The lack of good prediction models is due to the inherent variability of composites.

Key concerns in the use of composites that make prediction modeling difficult include:

- Epoxy coatings may delaminate in saltwater.
- Plastic mooring lines, especially nylon, degrade over time in saltwater.
- Flexibility properties change rather dramatically with temperature, so a material that is very pliable at 15°C may be stiff and brittle at -10°C.
- Plastics are generally anisotropic in their properties (depending on the orientation and concentration of the fibers), which should be addressed by design and fabrication recommendations.
- Polysulfide sealants can be rapidly disintegrated by bacteria under some conditions.

11.4. Anchoring and Mooring Safety and Regulatory Gap

11.4.1 Compliant Mooring Cables with Electrical Conductors for Wave and Current Devices

A potential problem exists in the interface between mooring systems and the electrical transmission systems for wave and current devices. At present, research is underway on compliant cables for connecting surface or subsurface generators to equipment on the sea floor. A new technology is now being used to supply compliant mooring elements with electrical and fiber-optic conductors to connect a surface buoy with underwater sensors for scientific and monitoring applications. This new technology relies on a new stretch-hose technology with synthetic fiber strength cords and electrical and fiber optic cables imbedded in the hose. The technology has not yet been developed with the strength to moor the moderate-sized structures needed for the conductors required to carry the high power output expected from wave and current power generating devices. These compliant cables appear to be a leading candidate technology for wave and current device power transmission to the sea floor because surface-moored wave and current energy devices will most likely be deployed with taut mooring systems (see exhibit 9-7).

11.5. Operations Management Safety and Regulatory Gaps

11.5.1. Accurate Risk Assessments and Emergency Response Planning

The absence of direct experience in wave and current energy conversion and the reliance of expertise from related marine industries is going to necessitate the best possible planning and risk analysis prior to the commencement of operations. The paradox is that it will present a challenge to develop accurate safety and risk assessments based on this lack of experience. This reality may require added steps in the planning process, such as simulation modeling and the deployment of scaled equipment to sites for testing purposes. Emergency response planning will face the same challenges. Added levels of safety in emergency response planning may need to be considered with, an emphasis on search and rescue operations.

11.5.2. Navigational Safety

The impact of marine renewable energy facilities on safe navigation is a major concern. Wave and current energy conversion devices differ from offshore wind because they could be entirely submerged (with the exception of signaling and communication devices). The U.S. Coast Guard does not have a robust policy in place yet. There are presently two helpful documents published in the United Kingdom that address navigational issues. The Maritime Coastguard Agency has a guidance note published addressing this issue:

> Marine Guidance Note 275 – Proposed UK Offshore Renewable Energy Installations (OREI) – Guidance on Navigational Safety Issues

Additionally, the U.K. Department of Trade and Industry (now known as BERR-Business Enterprise and Regulatory Reform) published the following document:

> Guidance on the Assessment of the Impact of Offshore Wind Farms -Methodology for Assessing the Marine Navigational Safety Risks of Offshore Wind Farms.

The U.S. Department of Energy awarded contracts in August 2008 in an effort to promote advanced waterpower technology. Under this funding, two separate efforts are being undertaken to assess the issues and make recommendations for hydrokinetic best siting practices. Some of the work of two of the companies involved – PCCI, Inc.[62], and Re Vision Consulting LLC[63] -- focuses on navigational impacts and recommended mitigation strategies. It is projected that both the BERR and MCA documents will be used to assist in the U.S. effort.

11.5.3. Competency Levels – Minimum Training Standards

There are presently no direct minimum training standards in place for this industry. Many of the skills required will be transferable from related maritime and power industries. However, this is an area where a concentrated effort is recommended.

[62] Alexandria, Virginia.
[63] Sacramento, California.

11.5.4. Diving Operations

By their nature, diving operations have a high level of base risk. Diving operations for offshore wave and current systems will have added complexity based on the ambient energy levels of the environment as well as subsea rotating and reciprocating equipment. The existing commercial diving procedures and regulations should be reviewed and specific provisions should be made for subsea operations on wave and current generating systems.

11.5.5. Crane and Lifting Operations

The use of cranes and lifting procedures will be a common practice in the maintenance of many wave and current installations. These high-risk operations will be taking place from both fixed and floating platforms. A majority of the lifting operations is projected to involve equipment retrieval onto a barge or specialized watercraft that will then either be serviced in place or transported to a shore-based facility for service. The API Recommended Practice RP 2D as incorporated into the Minerals Management Service (MMS) standards by 30 CFR 250.198 covers the operation and maintenance of offshore cranes for conventional MMS operations and could be used as a guideline in this area. There appears to be an adequate level of protection in the form of regulations and guidance, so this area not a clear gap. However, it is noted as a concern, and increased attention should be paid to these operations because the new technology deployed may require some non-standard crane and lifting operations.

11.5.6. Operating Performance

Free Flow Energy recommends that MMS have an equivalent method of gauging an operator’s performance, as described under 30 CFR 250.136, for conventional operations. The biggest changes will be the nature of the incidents and the regulations that the operator is being evaluated against. (See the detailed engineering candidate standards list in appendix A.) Based on the novel nature of this industry, it is projected that there will be multiple lessons learned by both the developers and the regulators. To facilitate the successful development of this industry, it is recommended a self-reporting system be incorporated into determination of the operating performance such that the operator can reduce the chances of punitive action. A self-reporting system would also encourage companies to practice full disclosure of their activities. This type of communication could – and should – be shared, since it would benefit the industry in general and promote its maturity. This is identified as a gap because a system of this nature presently does not exist for this industry.

Chapter 12. Recommended Research Initiatives

12.1. Recommended Wave and Current Energy Conversion Device Research Initiatives

Engineering concerns revolve around the current lack of specific design and construction standards for wave and current energy conversion technology. This is not only a safety-related concern, it is also an economic one. The absence of specific guidance increases the risks associated with developing this industry and thereby reduces its investment potential at a time when financial markets are under considerable stress and thus are risk averse. Consequently, the lack of specific standards is a major barrier to advancing this industry.

In addition, three general industry observations stand out:

1. The European Marine Energy Centre (EMEC) and the International Electrotechnical Commission (IEC) are presently working diligently on developing standards and guidance. Many of the standards are either under development or still in the draft stage. However, in an effort to encompass the variety of technology under development, these standards are very broad in scope and consequently lack a degree of specificity, which compromises their direct applicability.

2. Individual technology developers are trying to advance their own designs with little communication taking place between developers. Most of the companies are not well financed, and many are struggling to advance their designs.

3. Colleges and universities possess a crucial feedstock of skills and research capability to help this industry advance, yet these institutions are seeking limited funding to pursue their individual programs and are not coordinating their efforts.

Based on the lack of specific standards, the observations above, and the safety and regulatory gaps identified in chapter 11, the engineering research initiatives discussed below are recommended.

12.1.1 Better Collaboration Between Academic Institutions

Encourage both industry and academic institutions to form joint ventures for the development of regional maritime renewable energy centers. This will help ensure the maximum return on any investment into the research community. Although the 2008 advanced-water projects funded by the U.S. Department of Energy included support for the establishment of national marine renewable energy centers, greater emphasis should be placed on encouraging academic institutions to collaborate rather than compete.

12.1.2 Increased Coordination of International Efforts

Encourage the coordination of international efforts. Participants in this coordinated effort should include but not necessarily be limited to technology developers, academic institutions, power industry professionals, maritime professionals, and regulatory agencies. The IEC via Technical Committee 114, the International Energy Agency-Ocean Energy Systems, and EMEC are incorporating international efforts, but there is an opportunity to enhance this coordination.

12.1.3 Identification of Leading Technologies

Innovation should be encouraged, but there are so many technology developers, it is actually slowing the progress of this industry by diluting investment capital. The reality is many of these technology companies will not advance beyond the scaled-prototype stage of development. There is a need to narrow the field of participants in the marine renewable energy field to qualified organizations that are capable of full-scale implementation of their technology. In turn, the most qualified technology developers with the best designs can play a greater role in forming the specific regulatory structure needed. The research initiative recommended to facilitate this is the development of an impartial selection team and process to identify the leading technologies. This process would also encourage investment because it would enable investors to conduct an accurate comparative analysis of companies. EMEC is developing performance standards that will help evaluate these technologies. However, it is still up to the technology developer to accurately communicate the results of their equipment using these performance standards. Additionally, not all equipment will be evaluated at one test facility, thus broadening the possible variance of reported results.

12.1.4 Increase Awareness and Availability of Standards

Total compliance with the applicable regulations and design standards is a goal that both technology companies and regulators should strive to meet. To achieve this goal, technology developers need the assistance of regulators in identifying the relevant standards to follow. The intent of this report – attempt to identify relevant and non-relevant standards – directly supports this goal. In addition to assisting contractors identify the relevant standards, actions should be evaluated that would decrease the costs of some of these standards and thereby increase their availability and use within the industry.

12.1.5 Cursory Evaluation of OCS Wave and Current Resources From Existing Information

Conduct a review and analysis of existing scientific data available in the public domain to provide some realistic and verifiable assessment of wave and current potential on the Outer Continental Shelf. This information would aid MMS in managing the resources to both optimize public interest and encourage smarter ocean energy development. In the absence of this analysis, MMS has to rely on information that may not be objective.

12.1.6 Study of Shore-Based Support Requirements

A study of the shore-based requirements for the ocean energy industry along with an analysis of existing infrastructure will assist in the development of this industry. Potential developers will eventually conduct similar studies on a project specific basis. However, more advanced planning on a strategic level by regulators would assist and accelerate the development of this industry.

12.2. Recommended Electrical Transmission and Interface Research Initiatives

12.2.1 Grid Interface Feasibility Study and Comparative Analysis to OCS Ocean Energy Resources

The aging U.S. power grid, designed long ago and enduring constant revisions and upgrades, may not be adequate to support power originating from the ocean in the key areas of development. Research into grid capabilities could have widespread implications. It is recommended a study of this capacity be conducted with a focus placed on grid-tie in locations in comparison to sites where there is a realistic potential for ocean energy extraction. The feasibility studies would, in due course, be conducted by developers interested in specific sites. A more programmatic approach to this issue carried out by regulatory bodies could allow for earlier identification of problems. Consequently, solutions could be developed and implemented ahead of time to facilitate success of this industry.

12.2.2. Identification of Existing Cable Systems for Use in OCS Alternative Energy Operations

As discussed earlier, the costs of installing subsea transmission cabling to OCS wave and current sites could be prohibitively expensive for many potential developments. It is recommended a study be conducted of existing subsea cable systems that are either presently in use or abandoned that could be potentially used in support of ocean energy development.

12.2.3 Receptacle Connections

As mentioned in Section 11.2.4, there is a safety concern based on the lack of development of subsea receptacle arrangements that will safely accommodate the needs of wave and current devices. A research initiative is recommended to develop safer technology and methods of subsea electrical connections that will function with a high degree of reliability but also allow for easy disconnections and reconnections for servicing the wave and current devices.

12.3. Recommended Structural Research Initiatives

12.3.1. Recommended Concrete Research Initiatives

Research needs to be performed on the effects of aggregate and admixtures to prevent or minimize chemical deterioration of concrete and corrosion of reinforcing steel in the marine environment. Manufacturing corrosion-resistant reinforcing bars must be accomplished at a comparable price to ordinary steel reinforcing bars – or provide benefits that justify the higher cost.

Another area that needs further study is effective surface preparation methods for repairs. These methods should consider the environmental impact of use in a sensitive, coastal marine area.

A documented database of performance of cathodic protection techniques in the splash zone – such as imbedded zinc anodes, spray-applied zinc/titanium, and titanium rods and ribbons – might be of special interest.

12.3.2. Recommended Steel Research Initiatives

The specifications for steel coatings in the marine environment, specifically in the splash zone/intertidal area, need further research.

Investigation of newer splash-zone coatings and a comparison of these to standard methods in use today should be initiated (epoxy or epoxy/urethane, coal tar epoxy, etc.). Also thermal spray coatings should be investigated. Specifications should be improved for the use of steel coatings and their application to the marine environment, especially in the splash zone/intertidal area:

12.3.3. Recommended Composites Research Initiatives

Design guidance is needed for offshore structural engineers who wish to use composites in structures. Standard process specifications and tooling methods are required.

Designing the structure requires documented design methods, standardized test methods, verified failure criteria and a database of material properties. After the offshore structure is manufactured, it must pass through quality control procedures to inspect for defects. Inspection criteria need to be standardized. Many of these standards and procedures have been developed for the military aerospace industry. These methods must now be modified and developed for the offshore marine construction sector. In this sector there will be less concern with very small tolerances and more concern with low cost and large volume.

Although fiber-reinforced polymer (FRP) materials are typically more resistant to weathering or chemical attacks than steel, some durability concerns still arise in the presence of concrete or ultra-violet rays. Specifications of coating and UV treatment should be clarified at length.

12.3.4. Recommended Fatigue Research Initiatives

For the future, it will be necessary to develop aging models for materials so the chemical effect of the service environment can be determined and the aging model integrated with the mechanical fatigue life calculations shown here. It is a weakness of the current approach that fatigue is generally determined based on materials tests on new unaged material, whereas in reality fatigue would occur after some years of service. In that case, the fatigue behavior of the material should be characterized. This is best done on a geometry-free basis. For example if the crack growth rate is measured as a function of the energy available to cause crack growth (G or J) then a material’s relation is available against which the performance of the material can be assessed.

The development of fracture mechanics techniques structures is now well established, and their application to those geometrical cases for which there are verified solutions has generally proven successful. This has played an important part in developing confidence among engineers in the use of these materials in critical applications. For the future, the challenge is to automate the approach so that the fatigue-life calculations can become an integral part of the initial design process – with design and material selection being optimized for fatigue resistance.

Safety factors are currently used that will probably be seen as unrealistically conservative when a more quantitative approach is widely available.

Conscious design of the structure to achieve smooth stress flow through the structural details most likely will reduce the fatigue phenomenon.

12.4. Recommended Anchoring and Mooring Research Initiative

12.4.1 Mooring Cables and Power Umbilical Interface For Wave and Current Devices

As mentioned in Section 11.4.1, the interface between the power cabling and mooring lines is a source of concern, and no research is being conducted directly for wave and current devices. A research initiative is recommended to evaluate and adapt the technological advances made in mooring arrangements with embedded conductors to the wave and current energy industry. The evaluation would include an assessment to see if the existing technology could be scalable to address the needs of the wave and current industry.

12.5. Recommended Operations Management Research Initiatives

12.5.1. Operations Management Training Program

Based on the novel nature of this industry, it has been determined that the focus of the majority of wave and current energy devices developers primarily has been on development of their technology and less so on the operational planning and management of a mature energy installation. That being stated, one research initiative that would mutually benefit regulators and industry is a collaborative effort with industry to develop a programmatic Outer Continental Shelf (OCS) operations management training program for wave and current developers on the OCS. This program could utilize the existing commercial diving and platform expertise within the oil and gas industry as well as the regulatory expertise of MMS and other state and federal regulatory agencies, such as the U.S. Coast Guard. A program of this nature would assist in consistency of safe operations. Similarly, the British Wind Energy Association (BWEA) has introduced a training program that is a safety accreditation scheme for offshore renewable energy installations including wave and current devices. This training program contains the following modules (BWEA 2009a):

1. General Safety Passport
2. Marine Survival
3. Cranes (operations offshore)
4. Electrical Safety (HV awareness)
5. Management of Projects

12.5.2. Offshore Petroleum Industry Practices

The number of suitable sites for economically viable wave and current generation is limited. We do not think there will be widespread use of the wave and current energy generating devices in conjunction with existing platforms for oil and gas generation. However there are some oil and gas companies that are working with wave and current technology, and it is very possible that there will be limited deployments of these types of devices. For that reason, it is recommended that the American Petroleum Institute generate a recommended practice for use of these devices in association with oil and gas operations.

12.5.3. Creation of a U.S.-Based Implementation Task Force

To facilitate consistency of enforcement in this new area, it is recommended that a joint task force be formed of all U.S. regulatory stakeholders – including classification societies, USCG, the Federal Energy Regulatory Commission, MMS, and coastal state representation. The mission of this task force would be to agree on a consistent set of policies and procedures to be used for all hydrokinetic installations within U.S. territorial control. To enhance international collaboration, as mentioned in section 12.1.2, a secondary objective of this task force could be to directly interface with regulatory peers in other nations where there is aggressive development of hydrokinetic technology. There will be many changes in this industry over time, and the regulations are going to have to be adaptable. As an added advantage, this task force could recommend changes and improvements to the rules as operational experience is gained. The BWEA is adopting a similar strategy for maintenance operations. BWEA organizations jointly review work procedures and make recommendations to the rules based on operating experience (BWEA 2009b).

12.5.4. Navigational and General Impact Assessments

A navigation impact assessment should be conducted for all marine renewable energy installations. The complexity of this risk assessment will vary according to the volume of marine traffic, size of the energy facility, and many other variables. For complex navigation, impact assessments with high volumes of marine traffic, it is recommended to use existing bridge simulation facilities at maritime training centers to develop simulation programs for wave and current developments. Some of these facilities have a high degree of simulation capability, which could also be used for other risk assessments for this industry. Additionally, the feasibility of fitting offshore wave and current facilities with Automatic Identification Systems (AIS) to aid marine vessels in locating and navigating near these developments is recommended.

12.5.5. U.S.-Based Test Facility – Unification of Marine Renewable Effort

EMEC, located in the Orkney Islands of northern Scotland, is the leading test facility for tidal and wave energy equipment. EMEC is producing standards and laying groundwork to reinforce the United Kingdom's leadership role in this industry. Some U.S.-based academic institutions have made efforts to establish comparable facilities. The promotion of U.S.-based testing facilities for both wave and current devices would greatly benefit the industry.

PART V – APPENDICES

Appendix A – Candidate Engineering Standards Relevant to OCS Wave and Current Energy Conversion

Appendix B – Selected International Candidate Standards and Guidelines Related to Offshore Structures Design and Safety

Appendix C – Inspection and Monitoring Checklist: Existing (PINC) List Review

Appendix D – Selected Wave and Current Energy Conversion Device Developers

Appendix E – Report Exhibits

Appendix F – Report References and Sources

Appendix G – Contractors, Contributor, and Selected Consultations

Appendix H – Abbreviations and Acronyms

Appendix I – Patent Drawings

APPENDIX A. Candidate Engineering Standards Relevant to OCS Wave and Current Energy Conversion

The following is a list of candidate standards that have been identified as being relevant to OCS wave and current energy conversion. Before adopting these standards into regulation, a complete review of each standard is recommended. This list should not be considered authoritatively complete and should only be used for guidance. Some CFR that were considered peripheral to the industry were listed, however, the obvious CFR sections pertaining to MMS and/or the USCG (29,30,33,46 CFRs, etc.) were not listed.

Standard		Pre-Construction			Construction & Operation						Post-Construction
Organization - Publications	Title	Design, Test & Evaluation	Siting & Environmental Assessment	Classification, Certification & Insurance	Construction	Safety	Operation, Maintenance, Inspection & Monitoring	Anchoring, Mooring & Foundations	Electric Power, Transmission & Grid Interconnect	General and/or Statutory Regulation	Offshore Structures	Decommissioning
American Bureau of Shipping (ABS)	Guide for Building and Classing Facilities on Offshore Installations (Facilities Guide	X		X	X						X	
American Bureau of Shipping (ABS)	Guidance Notes on Reliability Centered Maintenance (2004)			X			X					
American Bureau of Shipping (ABS)	Guide for Building and Classing Floating Production Installations (FPI Guide	X		X	X						X	
American Bureau of Shipping (ABS)	Rules for Building and Classing Offshore Installations (Offshore Installations Rules)	X		X	X						X	
American Bureau of Shipping (ABS)	Rules for Building and Classing Single Point Moorings (SPM Rules)	X		X	X			X				
American Concrete Institute	ACI Standard 318-95, Building Code Requirements for Reinforced Concrete (ACI 318-95) and Commentary (ACI 318R-95)	X			X						X	
American Concrete Institute	ACI 357R-84, Guide for the Design and Construction of Fixed Offshore Concrete Structures, 1984, reapproved 1997	X			X						X	
American Institute of Steel Construction (AISC)	AISC Manual of Steel Construction – Allowable Stress Design.	X										
American Institute of Steel Construction (AISC)	AISC LRFD Manual of Steel Construction - Load and Resistance Factor Design	X										
American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME)	ANSI/ASME SPPE-1 Quality Assurance andn Certification of Safety and Pollution Prevention Equipment Usedin Oil and Gas Operations					X	X			X		
American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME)	ANSI/ASME B31.3 Process Piping	X			X							
American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME)	AGMA 6006-A03 (2004) - Standard or Design and Specification of Gear Boxes for Wind Turbines	X			X							
American Petroleum Institute (API)	API 17E / ISO 13628 Specification for Subsea Umbilicals	X			X	X			X			
American Petroleum Institute (API)	API Bull 2INT-EX - Interim Guidance for Design of Offshore Structures for Hurricane Conditions	X				X					X	
American Petroleum Institute (API)	API Bull 2TD, Guidelines for Tie-downs on Offshore Production Facilities for Hurricane Season	X									X	
American Petroleum Institute (API)	API RP 17N Recommended Practice. Subsea Production System Reliability &						X					
American Petroleum Institute (API)	API RP 2A – WSD Recommended Practice for Planning, Design and Constructing Fixed Offshore platforms, working stress design	X										
American Petroleum Institute (API)	API RP 2A Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms. Environmental Parameters for extreme response: inverse form with Omission factors, Winterstein, et. al. ISBN 9054103571	X										
American Petroleum Institute (API)	API RP 2C, Specification for Offshore Pedestal Mounted Cranes, Sixth Edition, March 2004, Effective Date: September 2004, API Stock No. G02C06					X	X					
American Petroleum Institute (API)	API RP 2D Recommended Practice for Operation and Maintenance of Offshore Cranes				X	X	X					

Standard		Pre-Construction			Construction & Operation							Post-Construction
Organization - Publications	Title	Design, Test & Evaluation	Siting & Environmental Assessment	Classification, Certification & Insurance	Construction	Safety	Operation, Maintenance, Inspection & Monitoring	Anchoring, Mooring & Foundations	Electric Power, Transmission & Grid Interconnect	General and/or Statutory Regulation	Offshore Structures	Decommissioning
American Petroleum Institute (API)	API RP 2FPS, Recommended Practice for Planning, Designing and Constructing Floating Production System	X										
American Petroleum Institute (API)	API RP 2SK, Design and Analysis of Stationkeeping Systems for Floating Structures	X										
American Petroleum Institute (API)	API RP 2T, Recommended Practice for Planning Designing and Constructing Tension Leg Platforms	X										
American Petroleum Institute (API)	Bull 2INT-MET - Interim Guidance on Hurricane Conditions in the Gulf of Mexico										X	
American Petroleum Institute (API)	Bulletin 2INT-DG, *Interim Guidance for Design of Offshore Structures for Hurricane Conditions*, covering how to apply the updated metocean data during design	X			X	X					X	
American Petroleum Institute (API)	Bulletin 2INT-EX, *Interim Guidance for Assessment of Existing Offshore Structures* for Hurricane Conditions, to assist owners/operators and engineers with existing facilities	X			X	X					X	
American Petroleum Institute (API)	API RP 95J, Gulf of Mexico Jackup Operations for Hurricane Season, Interim Recommendations, First Edition (API RP 95J)					X	X					
American Petroleum Institute (API)	API RP 14C API RecommendedPractice for Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms											
American Petroleum Institute (API)	RP 14F - Recommended Practice for Design and installation of Electical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Division 1, and Division 2 Locations	X										
American Petroleum Institute (API)	API RP 14J, Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities, Second Edition, API Stock no. G14J02	X				X						
American Petroleum Institute (API)	RP 2A-LRFD, Planning, Designing and Constructing Fixed Offshore Platforms—Load and Resistance Factor Design	X			X	X						
American Petroleum Institute (API)	RP 2A-LRFD-S1 Supplement 1 to Planning, Designing and Constructing Fixed Offshore	X			X	X						
American Petroleum Institute (API)	RP 2A-WSD Planning, Designing and Constructing Fixed Offshore Platforms—Working Stress Design	X										
American Petroleum Institute (API)	RP 2A-WSD-S2 Errata/Supplement 2 to Planning, Designing and Constructing Fixed Offshore Platforms	X										
American Petroleum Institute (API)	RP 2I In-service Inspection of Mooring Hardware for Floating Drilling Units						X	X				
American Petroleum Institute (API)	RP 2SM - Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring							X				
American Petroleum Institute (API)	API RP 2RD Design of Risers for Floating Production Systems (FPSs) and Tension ·Leg Platforms (TLPs) ISO / FDIS 2394 General Principles on Reliability for Structures	X			X						X	
American Petroleum Institute (API)	API RP 2SK, Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures, Third Edition, October 2005, API Stock G02RD1					X	X	X				

Standard		Pre-Construction			Construction & Operation							Post-Construction
Organization - Publications	Title	Design, Test & Evaluation	Siting & Environmental Assessment	Classification, Certification & Insurance	Construction	Safety	Operation, Maintenance, Inspection & Monitoring	Anchoring, Mooring & Foundations	Electric Power, Transmission & Grid Interconnect	General and/or Statutory Regulation	Offshore Structures	Decommissioning
American Petroleum Institute (API)	RP14J - Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities					X						
American Petroleum Institute (API)	Spec 2F Mooring Chain (ANSI/API Spec 2F-1997)	X						X				
American Petroleum Institute (API)	API RP T2 API Recommended Practice for Qualification Programs for Offshore Production Personnel Who Work With Anti-Pollution Safety Devices					X	X			X		
American Society of Mechanical Engineers	ASME Boiler & Pressure Vessel Code VIII/Div.1 (Applicable to Hydraulic Accummulators and energy storage devices- see also BS EN 13445)	X			X	X	X					
American Society for Testing and Materials	ASTM Standard C94/C 94M-99, Standard Specificationfor Ready-Mixed Concrete	X			X						X	
American Society for Testing and Materials	ASTM Standard 330-99, Standard Specification for Lightweight Aggregates for Structural Concrete	X			X						X	
American Society for Testing and Materials	ASTM A 48 7M Specification for Steel Casting: Suitable for Pressure Service	X			X						X	
American Society for Testing and Materials	ASTM G48 Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution	X					X				X	
American Society for Testing and Materials	ASTM Standard C150-99, Standard Specification for Portland Cement	X			X						X	
American Society for Testing and Materials	ASTM E562 Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count	X									X	
American Society for Testing and Materials	ASTM Standard 595-98, Standard Specificationfor Blended Hydraulic Cements	X			X						X	
American Society for Testing and Materials	ASTM Standard C 33-99a, Standard Specification for Concrete Aggregates	X			X						X	
American Welding Society	AWS D1.1:2000, Structural Welding Code - Steel	X			X						X	
American Welding Society	ANSI / AWS 01.1 Structural Welding. Code - Steel	X			X		X				X	
American Welding Society	AWS D1.4-98, Structural Welding Code- Reinforcing Steel	X			X						X	
American Welding Society	AWS D3.6M:1999, Specification for Underwater Welding	X			X						X	
British Standards Institute (BSI)	BS 2853 The Design and Testing of Steel Overhead Runway Beams.	X					X					
British Standards Institute (BSI)	BS 6349 Maritime structures. Code of practice for general criteria										X	
British Standards Institute (BSI)	BS EN 60255-22-3:2008 Measuring relays and protection equipment. Electrical disturbance tests. Radiated electromagnetic field immunity								X			
British Standards Institute (BSI)	BS 7448-2 Fracture mechanics toughness tests. Method for determination of Klc, critical CTOD and critical J values of welds in metallic materials	X					X				X	
British Standards Institute (BSI)	BS 7608 Code of practice for fatigue design and assessment of steel structures	X					X					
British Standards Institute (BSI)	BS 7910 Guide to methods for assessing the acceptability of flaws in metallic structures						X					
British Standards Institute (BSI)	BS 8100 Lattice Towers and Masts.	X										
British Standards Institute (BSI)	BS 8110 Structural Use of Concrete, Parts 1, 2 and 3.	X										
British Standards Institute (BSI)	BS 8118 Structural Use of Aluminium	X										

Standard		Pre-Construction			Construction & Operation							Post-Construction
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British Standards Institute (BSI)	BS 7910 Guide on methods for assessing the acceptability of flaws in fusion welded structures	X									X	
British Standards Institute (BSI)	BS EN 1993 Eurocode 3: Design of Steel Structures.	X										
British Standards Institute (BSI)	OHSAS 18001, OHSAS 18002 - Management System Guidance (see www.bsi-global.com)					X						
British Standards Institute (BSI)	BS EN 50091-1-1:1997 Uninterruptible power systems (UPS). General and safety requirements for UPS used in operator access areas, Parts 1 and2.	X				X			X			
Canadian Standards Association (CSA)	CSA S471 General Requirements, Design Criteria, the Environment and Loads.	X										
Canadian Standards Association (CSA)	CSA S474 Concrete Structures, Offshore Structures.										X	
Department of Labor	OSHA/U.S. Coast Guard Authority Over Vessels. OSHA Directive CPL 02-01-020 [CPL 2-1.20], (1996, November 8).						X			X		
Department of Labor	Memorandum of Understanding Between the Occupational Safety and Health Administration and the U.S. Coast Guard. OSHA Directive CPL 02-00-046 [CPL 2.46], (1982, January 20)						X			X		
Department of Labor	29 CFR PART 1917 - Marine Terminals									X		
Department of Labor	29 CFR PART 1918 - Safety and Health Regulations for Longshoring									X		
Department of Labor	29 cfr 1926.106 - Working over or near water.									X		
Department of Labor	29 CFR 1926 Subpart V - Power Transmission and Distribution								X	X		
Department of Labor	29 CFR 1926 Subpart Y - Commercial Diving Operations				X	X		X		X	X	
Department of Labor	29 CFR 1910 Subpart T - Commercial Diving Operations				X	X	X	X				

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Department of Labor	29 CFR 1926.912 - Underwater blasting.				X	X		X		X	X	
Department of Labor	29 CFR 1926 Subpart O - Motor Vehicles, Mechanized Equipment, and Marine Operations				X	X	X			X	X	
Department of Labor	29 CFR 1910.269 - Electric Power Generation, Transmission, and Distribution.					X			X			
Det Norske Veritas (DNV)	DnV RP A-203 Qualification of New Technology									X		
Det Norske Veritas (DNV)	DNV-OS-J101 "Design of Offshore Wind Turbines Structures"	X										
Det Norske Veritas (DNV)	DNV-OS-A101 Safety Principles and Arrangement, October 2005 [April 2008]					X			X			
Det Norske Veritas (DNV)	DNV-OS-B101 Metallic Materials										X	
Det Norske Veritas (DNV)	DNV-OS-C101 Design of Offshore Steel Structures, General (LRFD method), April 2004 [October 2007]										X	
Det Norske Veritas (DNV)	DNV-OS-C103 Structural Design of Column Stabilised Units (LRFD method), April 2004 [October 2007]										X	
Det Norske Veritas (DNV)	DNV-OS-C104 Structural Design of Self-elevating Units (LRFD method), October 2004 [October 2007]										X	
Det Norske Veritas (DNV)	DNV-OS-C105 Structural Design of TLPs (LRFD method), October 2005 [April 2007]										X	
Det Norske Veritas (DNV)	DNV-OS-C106 Structural Design of Deep Draught Floating Units (LRFD method), January 2001 [April 2007										X	
Det Norske Veritas (DNV)	DNV-OS-C201 Structural Design of Offshore Units (WSD method), April 2005 [April 2008										X	
Det Norske Veritas (DNV)	DNV-0S-D201:October 2008: Electrical Installations	X				X			X			
Det Norske Veritas (DNV)	DNV-OS-C301 Stability and Watertight Integrity	X				X	X				X	
Det Norske Veritas (DNV)	DNV-OS-F201. DYNAMIC RISERS (Global Load Effect Analysis Guidelines as it pertains to umbilicals)	X							X			
Det Norske Veritas (DNV)	DNV-OS-C401, Chapter 2						X					
Det Norske Veritas (DNV)	DNV-OS-C501 Composite Components, January 2007 (See Section 11 For Inspection)						X				X	

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Det Norske Veritas (DNV)	DNV-OS-C502 Offshore Concrete Structures, April 2007 (See Section 7 For Inspection)						X				X	
Det Norske Veritas (DNV)	DNV-OS-D101 Marine and Machinery Systems and Equipment, October 2005 [October 2007]	X										
Det Norske Veritas (DNV)	DNV-OS-D201 Electrical Installations, January 2008								X			
Det Norske Veritas (DNV)	DNV-OS-D202 AUTOMATION, SAFETY, AND TELECOMMUNICATION SYSTEMS OCTOBER 2008	X				X			X			
Det Norske Veritas (DNV)	DNV-OS-D301 Fire Protection, October 2005 [October 2007]					X						
Det Norske Veritas (DNV)	DNV-OS-E301 Position Mooring, October 2004 [April 2007]							X				
Det Norske Veritas (DNV)	DNV-OS-E303 Certification of Fibre Ropes for Offshore Mooring, April 2008							X				
Det Norske Veritas (DNV)	DNV-OS-E403 Offshore Loading Buoys, April 2005							X				
Det Norske Veritas (DNV)	DNV-RP-C203 Fatigue Design of Offshore Steel Structures	X										
Det Norske Veritas (DNV)	DNV-RP-E305: Onbottom Stability of Design of Submarine Pipelines (Also relevant to subsea cables)	X			X				X			
Det Norske Veritas (DNV)	DNV CN 41.2 Calculation of Gear Rating for Marine Transmissions (Classification Note)	X										
Det Norske Veritas (DNV)	DNV CN 30.6 Structural Reliability Analysis of Marine Structures (Classification Note)			X		X					X	
Det Norske Veritas (DNV)	DNV-RP-H101 Risk Management in Marine and Subsea Operations					X						
Det Norske Veritas (DNV)	DNV-RP-A202 Documentation of Offshore Projects											
Det Norske Veritas (DNV)	DNV-RP-C204 Design Against Accidental Loads	X				X					X	
European Marine Equipment Council (EMEC) - Draft standards	Assessment of Performance of Tidal Energy Conversion Systems	X										
European Marine Equipment Council (EMEC) - Draft standards	Assessment of Performance of Wave Conversion Systems	X										
European Marine Equipment Council (EMEC) - Draft standards	Assessment of Tidal Energy Source		X									
European Marine Equipment Council (EMEC) - Draft standards	Assessment of Wave Energy Resource		X									
European Marine Equipment Council (EMEC) - Draft standards	Guidelines for Design Basis of Marine Energy Conversion Systems											
European Marine Equipment Council (EMEC) - Draft standards	Guidelines for Environmental Appraisal in the Marine Energy Industry		X									
European Marine Equipment Council (EMEC) - Draft standards	Guidelines for Grid Connection of Marine Energy Conversion Systems								X			
European Marine Equipment Council (EMEC) - Draft standards	Guidelines for Health & Safety in the Marine Energy Industry					X						
European Marine Equipment Council (EMEC) - Draft standards	Guidelines for Manufacturing, Assembly, and Testing of Marine Energy Conversion Systems	X										
European Marine Equipment Council (EMEC) - Draft standards	Guidelines for Marine Energy Certification Schemes			X								
European Marine Equipment Council (EMEC) - Draft standards	Guidelines for Project Development in the Marine Energy Industry									X		
European Marine Equipment Council (EMEC) - Draft standards	Guidelines for Reliability, Maintainability, and Survivability of Marine Energy Conversion Systems	X					X					
European Marine Equipment Council (EMEC) - Draft standards	Tank Testing of Tidal Energy Conversion Systems	X										
European Marine Equipment Council (EMEC) - Draft standards	Tank Testing of Wave Energy Conversion Systems	X										

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Federal Energy Regulatory Commission	Small Generator Interconnection Procedures (SGIP)						X		X			
Federal Energy Regulatory Commission	Standard Large Generator Interconnection Procedures (LGIP) - Applicable to Generating Facilities that exceed 20 MW.						X		X			
Germanischer Lloyds Classification Society	Equipment Certification Program for Marine Renewable Energy Systems			X								
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA Code 1061 On Light Applications Illumination of Structures December 2008	X	X		X	X						
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA Code 1048 On LED Technologies and their use in Signal Lights	X				X						
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA Code 1044 On Secondary Batteries for Aids to Navigation	X	X		X	X						
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA 1028 On the Universal Automatic Identification System (AIS) - Volume 1 - Part 1 Operational issues (Dec 2002 - Revised Dec 2004)	X				X	X			X		
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA 1035 On Availability and Reliability of Aids to Navigation	X				X	X			X		
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA Code 1036 On Environmental Consideration in Aids to Navigation Engineering	X				X	X			X		
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA Code 1038 On ambient light levels at which aids to navigation should switch on and off	X				X	X			X		
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA Code 1039 On Designing Solar Power Systems for Aids to Navigation (excel sheet available on request)	X				X	X			X		
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA Code 1042 On Power Sources used in Visual Aids to Navigation - Replaces 1022	X				X	X			X		
International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)	IALA Code 1008 On remote monitoring and control of aids to navigation	X				X	X			X		
International Maritime Organization (IMO) - Marine Environment Protection Committee	International Convention on the Control of Harmful Anti-Fouling Systems (IAFS)									X		
International Electrotechnical Commission (IEC)	IEC 60092–350 Low-voltage shipboard power cables. General construction and test requirements								X			
International Electrotechnical Commission (IEC)	IEC 60092–353 Single and multicore non-radial field power cables with extruded solid insulation for rated voltages 1 kV and 3 kV								X			
International Electrotechnical Commission (IEC)	IEC 60092–354 Single and three-core power cables with extruded solid insulation for rated voltages 6 kV, 10 kV and 15 kV								X			
International Electrotechnical Commission (IEC)	IEC 60092–375 Shipboard telecommunication cables and radio frequency cables – General instrumentation, control and communication cables								X			
International Electrotechnical Commission (IEC)	IEC 60092–376 Shipboard multicore cables for control circuits								X			
International Electrotechnical Commission (IEC)	IEC 60146 Semiconductor Inverters	X				X			X			
International Electrotechnical Commission (IEC)	IEC 60255 Electrical relays								X			
International Electrotechnical Commission (IEC)	IEC 60269 Low-voltage fuses;								X			

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International Electrotechnical Commission (IEC)	IEC 60282-1 High voltage fuses Pt 1: Current-limiting fuses;								X			
International Electrotechnical Commission (IEC)	IEC 60298 AC Metal enclosed switchgear and control gear for rated voltages above 1 kV and up to and including 72.5 kV								X			
International Electrotechnical Commission (IEC)	IEC 60300-3-11 Dependability Management-Part 3-11: Application Guide-Reliability Centered Maintenance						X					
International Electrotechnical Commission (IEC)	IEC 60308 ED. 2.0 B:2005 Hydraulic turbines - Testing of control systems						X					
International Electrotechnical Commission (IEC)	IEC 60466 AC insulated-enclosed switchgear for rated voltages above 1 kV and up to and including 38 kV;								X			
International Electrotechnical Commission (IEC)	IEC 60470 High-voltage alternating current contactors.								X			
International Electrotechnical Commission (IEC)	IEC 60502 Power cables with extruded insulation and their accessories								X			
International Electrotechnical Commission (IEC)	IEC 60702 Mineral insulated cables with a rated voltage not exceeding 750 V								X			
International Electrotechnical Commission (IEC)	IEC 60947-2 Low voltage switchgear and Control gear Pt 2: Circuit-breakers;				X				X			
International Electrotechnical Commission (IEC)	IEC 61400-3 standard "Design Requirement for Offshore Wind Turbines"	X										
International Electrotechnical Commission (IEC)	IEC 60439-1 Low Voltage Equipment	X				X			X			
International Electrotechnical Commission (IEC)	IEC 61508 part 3. Functional safety of electrical/electronic/programmable electronic safety-related systems -	X				X			X			
International Electrotechnical Commission (IEC)	IEC 60545 (1976-01) Guide forcommissiong, operation, and maintenance of hydraulic turbines						X					
International Electrotechnical Commission (IEC)	IEC 60609 (1978-01) Cavitation pitting evaluation in hydraulic turbines, storage pumps,and pump turbines						X					
International Electrotechnical Commission (IEC)	IEC 60609-2 (1997-11) Cavitation pitting evaluation in hydraulic turbines, storage pumps,and pump turbines - Part 2: Evaluation in Pelton Turbines						X					
International Electrotechnical Commission (IEC)	IEC 610004-2 Ed. 1.2 b:2001 Electromagnetic compatibility (EMC)	X				X			X			
International Electrotechnical Commission (IEC)	BS IEC 61366-1:1998 Hydraulic turbines, storage pumps, and pump turbines. Tendering documents. General and annexes	X			X		X					
International Electrotechnical Commission (IEC)	IEC 61378 Convertor Transformers	X				X			X			
International Electrotechnical Commission (IEC)	IEC61400-1 Wind Turbine Generator Systems - Part 1: Safety Requirements					X						
International Electrotechnical Commission (IEC)	IEC 62271-100 High-voltage switchgear and control gear - Pt 100: High-voltage alternating-current circuit breakers;								X			
International Electrotechnical Commission (IEC)	IEC 12207 Systems and software engineering - - Software life cycle processes	X								X		
International Energy Agency (IEA)	IEA-Ocean Energy Systems - Annex III: Integration of Ocean Energy Plants into								X			
International Energy Agency (IEA)	IEA-Ocean Energy Systems 2007 Annual Report									X		
IEEE Standards Association	IEEE Std 1228-1994 IEEE Standard for Software Safety Plans					X				X		
IEEE Standards Association	P1547: Standard for Distributed Resources Interconnected with Electric Power Systems	X				X			X			

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IEEE Standards Association	IEEE STD 519-1992 IEEE Recommended Practices and Requirements For Harmonic Control in Electric Power Systems	X				X			X			
IEEE Standards Association	IEEE STD 929-2000 Static Inverters	X				X			X			
International Maritime Organization (IMO)	IMO Resolution A.753(18) Guidelines for the Application of Plastic Pipes on Ships	X										
International Organization for Standardization (ISO)	ISO 148 Steel- Charpy impact test (V-notch)	X									X	
International Organization for Standardization (ISO)	ISO 898 Mechanical properties of fasteners made of carbon and alloy steel	X			X						X	
International Organization for Standardization (ISO)	ISO 6507-1 Metallic materials - Vickers hardness test - Part 1: Test method	X										
International Organization for Standardization (ISO)	ISO 8501-1 Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness - Part 1: Rust erodes and preparation erodes of uncoated steel substrates and of steel substrates after overall removal of previous coatings				X		X				X	
International Organization for Standardization (ISO)	ISO 10042 Arc-welded joints in aluminum and its weldable alloys - Guidance on quality levels for imperfections	X			X		X				X	
International Organization for Standardization (ISO)	ISO 10380 Pipework – Corrugated metal hoses and hose assemblies	X										
International Organization for Standardization (ISO)	ISO 1328: Gear quality grade.	X										
International Organization for Standardization (ISO)	ISO / IEC 17020 General criteria for the operation of various types of bodies performing inspections						X					
International Organization for Standardization (ISO)	ISO 19900 General requirements for offshore structures (Petroleum and natural gas industries)										X	
International Organization for Standardization (ISO)	ISO 19901-1 Petroleum and natural gas industries -- Specific requirements for offshore structures -- Part 1: Metocean Design and Operating Considerations										X	
International Organization for Standardization (ISO)	ISO 19901-2 Specific requirements for offshore structures-- Part 2: Seismic design procedures and criteria										X	
International Organization for Standardization (ISO)	ISO 12944 CSM Paints and varnishes - Corrosion protection of steel structures by protective paint systems; marine, offshore, estuaries, coastal areas with high salinity						X				X	
International Organization for Standardization (ISO)	ISO 13819-1 Petroleum and natural gas industries - Offshore structures – Part 1: General requirements										X	
International Organization for Standardization (ISO)	ISO 14688 Geotechnical investigations and testing - identification and classification of soil Part 1: Identification and description.	X	X									
International Organization for Standardization (ISO)	ISO CD 19001-2 Seismic design procedures and criteria	X									X	
International Organization for Standardization (ISO)	ISO 19901-4 Specific requirements for offshore structures-- Part 4: Geotechnical and foundation design considerations (Petroleum and natural gas industries)										X	
International Organization for Standardization (ISO)	ISO 19902 Fixed steel offshore structures (Petroleum and natural gas industries)										X	

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International Organization for Standardization (ISO)	ISO 19903 Fixed concrete offshore structures (Petroleum and natural gas industries)										X	
International Organization for Standardization (ISO)	ISO 19904-1 Floating offshore structures -- Part 1: Monohulls, semi-submersibles and spars (Petroleum and natural gas industries.										X	
International Organization for Standardization (ISO)	ISO 281: Dynamic Load Ratings and Rating Life of Rolling Bearings.											
International Organization for Standardization (ISO)	ISO 6336: Calculation of load capacity of spur and helical gears.	X										
International Organization for Standardization (ISO)	ISO 6802 Rubber and plastics hoses and hose assemblies – Hydraulic pressure impulse test without flexing.	X										
International Organization for Standardization (ISO)	ISO 6803 Rubber and plastics hoses and hose assemblies – Hydraulic pressure impulse test with flexing.	X										
International Organization for Standardization (ISO)	ISO 76: Static Load Ratings for Rolling Bearings.	X										
International Organization for Standardization (ISO)	ISO 9000:2000 Achieving Registration, ISBN 0 580 40499 4			X								
International Organization for Standardization (ISO)	BS EN ISO 14001:2004 Environmental Management System Certification			X								
International Organization for Standardization (ISO)	ISO 13628-5 Design and operation of subsea production systems -- Part 5: Subsea umbilicals	X							X			
Lloyd's Register - Offshore Rules and Regulations	Rules & Regulations For The Classification Of A Floating Offshore Installation At A Fixed			X								
Lloyd's Register - Offshore Rules and Regulations	Rules & Regulations For The Classification Of Fixed Offshore Installations 1989 Full Set			X								
Lloyd's Register - Offshore Rules and Regulations	Rules & Regulations For The Classification Of Mobile Offshore Units			X								
Lloyd's Register - Offshore Rules and Regulations	Rules & Regulations For The Construction & Classification Of Submersibles & Underwater Systems			X								
Marine Coast Guard Agency	Marine Guidance Note - Offshore Renewable Energy Installations (OREIs) - Guidance on UK Navigational Practice, Safety and Emergency Response Issues		X			X				X		
Minerals Management Service (MMS)	NTL No. 2004-G06, Structure Removal Operations											X
Minerals Management Service (MMS)	MMS Peoject 549 - ASSESSMENT OF FIXED OFFSHORE PLATFORM PERFORMANCE IN HURRICANES ANDREW, LILI AND IVAN January 2006										X	
Minerals Management Service (MMS)	MMS Pojects 628 - (This Study) and 629 - (PCCI in progress) Assess the Design and Inspection Criteria and Standards for Wave and Current Energy Generating Devices						X					
Minerals Management Service (MMS)	MMS Project 067 - Rig Mooring Reliability							X				
Minerals Management Service (MMS)	MMS Project 116 - mpact of Annual Ice with a Cable-Moored Platform							X				
Minerals Management Service (MMS)	MMS Project 133 - Synthetic-Fiber Mooring Lines for Deepwater floating Production Facilities							X				
Minerals Management Service (MMS)	MMS Project 139 - Operation RIGMOOR							X				
Minerals Management Service (MMS)	MMS Project 194 - Calibration of Mooring Design Code for Floating Drilling and Production Platforms							X				
Minerals Management Service (MMS)	MMS Project 200 - Securing Procedures for Mobile Drilling Units (MODU's) in the Gulf of Mexico							X				

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Minerals Management Service (MMS)	MMS Project 238 - Recommended Procedure for Design of Drag-Embedment (Fluke) Anchors							X				
Minerals Management Service (MMS)	MMS Project 315 - Engineers Design Guide to Deepwater Fiber Moorings							X				
Minerals Management Service (MMS)	MMS Project 316 - Reliability Study for Synthetic Moorings							X				
Minerals Management Service (MMS)	MMS Project 344 - Durability of Polyester Rope Moorings							X				
Minerals Management Service (MMS)	MMS Project 362 - Deep Water Anchor Reliability							X				
Minerals Management Service (MMS)	MMS Project 366 - Dynamic Analysis Tool for Moored Tanker-Based FPSOs, including Large Yaw Motions							X				
Minerals Management Service (MMS)	MMS Project 368 - Response of Tanker Based FPSO to GOM Hurricanes							X				
Minerals Management Service (MMS)	MMS Project 369 - Polyester Rope Analysis Tool							X				
Minerals Management Service (MMS)	MMS Project 389 - Characterizing Polyester Rope Installation Damage							X				
Minerals Management Service (MMS)	MMS Project 394 - Interim Damage Criteria for Replacing Damaged Polyester Rope							X				
Minerals Management Service (MMS)	MMS Project 407 - Damage Tolerance of Synthetic-Fiber Mooring Ropes; Phase I: Small Scale Experiments							X				
Minerals Management Service (MMS)	MMS Project 407 - Damaged Polyester Rope-Large Scale Experiment							X				
Minerals Management Service (MMS)	MMS Project 423 - Foundation/Mooring Risk of FPSOs							X				
Minerals Management Service (MMS)	MMS Project 437 - Reliability Analysis of Deepwater Anchors							X				
Minerals Management Service (MMS)	MMS Project 447 - Qualifying Composite Tendons and Risers							X				
Minerals Management Service (MMS)	MMS Project 469 - Post Mortem Failure Assessment of Drilling Rigs During Hurricane Lili										X	
Minerals Management Service (MMS)	MMS Project 557 - Numerical Modeling of Torpedo Anchors							X				
Minerals Management Service (MMS)	MMS Project 575 - Torpedo Piles for Gulf of Mexico Applications							X				
Minerals Management Service (MMS)	MMS Project 578 - ASSESSMENT OF FIXED OFFSHORE PLATFORM PERFORMANCE IN HURRICANES KATRINA AND RITA - FINAL REPORT May 2007										X	
Minerals Management Service (MMS)	MMS Project 584 - Arctic Offshore Technology Assessment of Exploration and Production Options for Cold Regions of the US Outer Continental Shelf										X	
Minerals Management Service (MMS)	MMS Project 591 - Evaluate Accuracy of Polyester Subrope Damage Detection Performed by ROVs Following Hurricanes and Other Events							X				
Minerals Management Service (MMS)	MMS Project 592 - Connector Designs for Top and Bottom Tendon Connections							X				
Minerals Management Service (MMS)	MMS Project 603 - Stability of Tension Leg Platforms with Damaged Tendons							X				
Minerals Management Service (MMS)	MMS Project 604 - Evaluation of Fatigue Life Models and Assessment Practice for Tension Leg Platforms (Phase 1: Tendon System Fatigue)										X	
Minerals Management Service (MMS)	MMS Project 605 - Cooperative Research on Extreme Seas and their Impact to Floating Structures										X	

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National Association of Corrosion Engineers	NACE Standard Recommended Practice RP0387-87: "Metallurgical and Inspection Requirements for Cast Sacrificial Anodes for Offshore Applications"						X				X	
National Association of Corrosion Engineers	NACE Standard RP0176-2003, Item 21018, Standard Recommended Practice, Corrosion Control of Steel Fixed Offshore Structures Associated with Petroleum Production						X				X	
National Fire Protection Association	NFPA-70 The National Electrical Code, Article 705: Interconnected Electric Power Production Sources	X				X			X			
National Fire Protection Association	NFPA-110 Standard for Emergency and Standby Power Systems	X				X			X			
Norwegan Standard	NS 3473 Concrete Structures – Design Rules.	X										
NORSOK- Norwegian Technology Centre	E-001, REV 4, 2001-07-01 Electrical Systems (In addition to general electrical requirements, it also applies to UPS systems)	X							X			
NORSOK - Norwegian Technology Centre	NORSOK G-CR-001 Marine Soil investigations		X								X	
NORSOK - Norwegian Technology Centre	NORSOK N-003 Action and Action Effects					X						
NORSOK - Norwegian Technology Centre	NORSOKM-001 Material selection	X			X						X	
NORSOK - Norwegian Technology Centre	NORSOK N-004 Annex 4 Design of Steel Structures										X	
NORSOK - Norwegian Technology Centre	S-001 Technical Safety					X						
NORSOK - Norwegian Technology Centre	Z-007 Mechanical Completion and Commissioning				X							
NERC - North American Electrical Reliability Corporation	Standard BAL-005-0b - Automatic Generation Control						X		X			
NERC - North American Electrical Reliability Corporation	Standard CIP-001-1 - Sabotage Reporting						X		X			
NERC - North American Electrical Reliability Corporation	Standard CIP-002-1 - Cyber Security - Critical Cyber Asset Identification						X		X			

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NERC - North American Electrical Reliability Corporation	Standard CIP-003-1 - Cyber Security-Security Management Controls						X		X			
NERC - North American Electrical Reliability Corporation	Standard CIP-004-1 - Cyber Security - Personnel and Training						X		X			
NERC - North American Electrical Reliability Corporation	Standard CIP-005-1 - Cyber Security - Electronic Security Perimeters						X		X			
NERC - North American Electrical Reliability Corporation	Standard CIP-006-1 - Cyber Security - Physical Security						X		X			
NERC - North American Electrical Reliability Corporation	StandardCIP-006-1a - Cyber Security-Physical Security of Critical Cyber Assets						X		X			
NERC - North American Electrical Reliability Corporation	Standard CIP-007-1 - Cyber Security - Systems Security Management						X		X			
NERC - North American Electrical Reliability Corporation	Standard CIP-008-1 - Cyber Security - Incident Reporting and Response						X		X			
NERC - North American Electrical Reliability Corporation	Standard CIP-009-1 - Cyber Security - Recovery Plansfor Critical Cyber Assets						X		X			
NERC - North American Electrical Reliability Corporation	Standard COM-00202 - Communications and Coordination						X		X			
NERC - North American Electrical Reliability Corporation	Standard EOP-004-1 - Disturbance Reporting						X		X			
NERC - North American Electrical Reliability Corporation	Standard EOP-009-0 - Documentation of Blackstart Generating Unit Test Results						X		X			
NERC - North American Electrical Reliability Corporation	Standard FAC-002-0 - Coordination of Plans for New Facilities						X		X			
NERC - North American Electrical Reliability Corporation	Standard FAC-008-1 - Facility Ratings Methodology						X		X			
NERC - North American Electrical Reliability Corporation	Standard IRO-001-1 Reliability Coordination - Responsibilities and Authorities						X		X			

Standard		Pre-Construction			Construction & Operation							Post-Construction
Organization - Publications	Title	Design, Test & Evaluation	Siting & Environmental Assessment	Classification, Certification & Insurance	Construction	Safety	Operation, Maintenance, Inspection & Monitoring	Anchoring, Mooring & Foundations	Electric Power, Transmission & Grid Interconnect	General and/or Statutory Regulation	Offshore Structures	Decommissioning
NERC - North American Electrical Reliability Corporation	Standard IRO-004-1 - Reliability Coordination - Operations Planning						X		X			
NERC - North American Electrical Reliability Corporation	Standard IRO-005-02 - Reliability Coordination - Current Day Operations						X		X			
NERC - North American Electrical Reliability Corporation	Standard IRO-010-1 - Reliability Coordinator Data Specification and Collection						X		X			
NERC - North American Electrical Reliability Corporation	Standard NUC-001-1 - Nuclear Plant Interface Coordination						X		X			
NERC - North American Electrical Reliability Corporation	Standard PRC-001-1 - System Protection Coordination						X		X			
NERC - North American Electrical Reliability Corporation	Standard PRC-004-1 - Analysis and Mitigation of Transmission and Generation Protection System Misoperations						X		X			
NERC - North American Electrical Reliability Corporation	Standard PRC-005-1 - Transmission and Generation Protection System Maintenance and Testing						X		X			
NERC - North American Electrical Reliability Corporation	Standard PRC-015-0 - Special Protection System Data and Documentation						X		X			
NERC - North American Electrical Reliability Corporation	Standard PRC-017-0 - Special Protection System Maintenance and Testing						X		X			
NERC - North American Electrical Reliability Corporation	Standard PRC-018-1 - Disturbance Monitoring Equipment Installation and Data Reporting						X		X			
NERC - North American Electrical Reliability Corporation	Standard TOP-006-1 Monitoring System Conditions						X		X			
NERC - North American Electrical Reliability Corporation	Standard TOP-001-1 - Reliability Responsibilities and Authorities						X		X			
NERC - North American Electrical Reliability Corporation	Standard VAR-002-1a - Generator Operation for Maintaining Network Voltage Schedules						X		X			
NERC - North American Electrical Reliability Corporation	Standard TOP-002-2 - Normal Operations Planning						X		X			

Standard		Pre-Construction			Construction & Operation							Post-Construction
Organization - Publications	Title	Design, Test & Evaluation	Siting & Environmental Assessment	Classification, Certification & Insurance	Construction	Safety	Operation, Maintenance, Inspection & Monitoring	Anchoring, Mooring & Foundations	Electric Power, Transmission & Grid Interconnect	General and/or Statutory Regulation	Offshore Structures	Decommissioning
NERC - North American Electrical Reliability Corporation	Standard TOP-003-0 - Planned Outage Coordination						X		X			
Office Of Communications (OFCOM) (UK)	OFCOM Performance Specification MPT 1411	X				X	X					
SAE International	SAE-JA1011 (1999) - Evaluation Criteria for Reliability Centered Maintenance Processes						X					
SAE International	SAE-JA1012 (1999) - A Guide to Reliability Centered Maintenance						X					
UK Health and Executive Safety	Offshore Technology Report 2000/099 Generic design framework pile foundations (fixed steel structures) ISBN 0 7176 2039 5	X										
UK Health and Executive Safety	Offshore Technology Report 2001/032 Decommissioning Topic Strategy ISBN 0 7176 2054 9											X
UK Office of Public Sector Information	Electricity Safety, Quality and Continuity Regulations (2002) (Section J – Generation). Publication reference URN 02/1544					X						
UK Office of Public Sector Information	Engineering Recommendation G5/4-1. Issue 1. Planning Levels for harmonic Voltage Distortion and the Connection of Non-Linear Equipment to Transmission Systems and Distribution Networks in the United Kingdom. 2005								X			
UK Office of Public Sector Information	Engineering Recommendation G59/1. Issue 1. Recommendations for the connection of embedded generating plant to the Public Electricity Suppliers distribution systems.								X			
UK Office of Public Sector Information	Engineering Recommendation G74. Issue 1. Procedure to meet the requirements of IEC 909 for the calculation of short-circuit currents in three-phase AC power systems. 1992								X			
UK Office of Public Sector Information	Engineering Recommendation G75/1. Issue 2. Recommendations for the connection of embedded generating plant to Public distribution systems above 20kV or with outputs over 5MW. 2002								X			
UK Office of Public Sector Information	Engineering Recommendation P28. Issue 1. Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the United Kingdom. 1989.								X			
UK Office of Public Sector Information	Engineering Recommendation P29. Issue 1. Planning limits for voltage unbalance in the UK for 132kV and below. 1990.								X			
UK Office of Public Sector Information	G59/1 Recommendations For The Connection Of Private Generating Plant To The Regional Electricity Companies								X			
UK Office of Public Sector Information	G75 Recommendations for the Connection of Embedded Generating Plant to Public Electricity Suppliers Distribution Systems (above 20kV or with outputs over 5MW)								X			

Standard		Pre-Construction			Construction & Operation							Post-Construction
Organization - Publications	**Title**	**Design, Test & Evaluation**	**Siting & Environmental Assessment**	**Classification, Certification & Insurance**	**Construction**	**Safety**	**Operation, Maintenance, Inspection & Monitoring**	**Anchoring, Mooring & Foundations**	**Electric Power, Transmission & Grid Interconnect**	**General and/or Statutory Regulation**	**Offshore Structures**	**Decommissioning**
UK Office of Public Sector Information	Statutory Instrument 2002 No. 2665 The Electricity Safety, Quality and Continuity Regulations					X						
UK Office of Public Sector Information	Statutory Instrument 2006 No. 1521 The Electricity Safety, Quality and Continuity (Amendment) Regulations 2006					X						
U.S. Coast Guard	Navigation and Vessel Inspection Circular No. 01-05, Change 1. CH-1 to NVIC 01-05, Interim Guidance for the Development and Review of Response Plans for Nontank Vessels.									X		
UK Office of Public Sector Information	The Distribution Code and the Guide to the Distribution Code of Licensed Distribution Network Operators of Great Britain. Issue 08 HL: October 2006 (full version)								X			
UK Office of Public Sector Information	The Grid Code, Issue 3. Revision 25. 1st February 2008								X			

Appendix B – Selected International Candidate Standards and Guidelines Related to Offshore Structures Design and Safety[1]

API RP 14J	Design and Hazard Analysis for Offshore Production Facilities
ISO 10418	Petroleum and natural gas industries - Offshore production platforms - Analysis, design, installation and testing of basic surface safety systems
Design of Offshore Steel Structures, General/ LRFD method)	AISC LRFD Manual of Steel Construction API RP 2A LRFD Planning, Designing, and Constructing Fixed Offshore Platforms - Load and Resistance Factor Design BS 7910 Guide on methods for assessing the acceptability of flaws in fusion welded structures Eurocode 3 Design of Steel Structures ISO 13819-1 Petroleum and natural gas industries - Offshore structures – Part 1: General requirements NORSOK N-003 Actions and Action Effects NORSOK N-004 Design of Steel Structures
Fabrication and Testing of Offshore Structures	ANSI / AWS 01.1 Structural Welding. Code - Steel ASME Section IX, Welding. and Brazing Qualifications Non-Interfiled (Boiler and Pressure Vessel Codes) ASTM G48 Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution ASTM E562 Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count BS 7448-2 Fracture mechanics toughness tests. Method for determination of Klc, critical CTOD and critical J values of welds in metallic materials EN 287 Approval testing. of welders - Fusion welding EN 1418 Welding. personnel - Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials lACS Shipbuilding and Repair Quality Standard, Part A - Shipbuilding and repair Quality Standard for New Construction and Part B - Repair Quality Standard for Existing Ships ISO 148 Steel- Charpy impact test (V-notch) ISO 898 Mechanical properties of fasteners made of carbon and alloy steel ISO 6507-1 Metallic materials - Vickers hardness test - Part 1: Test method

[1] From Det Norske Veritas (DNV) “Guidelines on Design and Operation of Wave Energy Converters.”

	ISO 8501-1 Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness - Part 1: Rust erodes and preparation erodes of uncoated steel substrates and of steel substrates after overall removal of previous coatings ISO 9001 :2000 Quality management systems - Requirements ISO 9606 Approval testing of welders - Fusion welding ISO 10042 Arc-welded joints in aluminum and its weldable alloys - Guidance on quality levels for imperfections
Composite Components	API RP 2RD Design of Risers for Floating Production Systems (FPSs) and Tension ·Leg Platforms (TLPs) ISO / FDlS 2394 General Principles on Reliability for Structures
Offshore Concrete Structures	ISO 13819-1 Petroleum and natural gas industries - Offshore structures - Part 1: General requirements NORSOK N-003 Actions and Action Effects NORSOK N-004 Design of Steel Structures
Position Mooring	ASTM A 48 7M Specification *for* Steel Casting: Suitable for Pressure Service API RP 2A-LRFD Planning Designing, and Construction of Fixed Offshore Platforms - Load and Resistance Factor Design API RP 2A-WSO Planning Designing, and Construction of Fixed Offshore Platforms - Working Stress Design API Spec 2F Mooring, Chain API RP 2SK Design and Analysis of Station keeping Systems *for* Floating Structures API RP 29.\ Recommended Practice for Design, Analysis, and Testing of Synthetic Fiber Ropes in Offshore Applications BS 3226 Specification *for* thimbles *for* natural fiber ropes, 1960 BS 7035 Code of practice for docketing of stranded steel wire ropes, 1989. C11505-98 Test Method for Yarn-on-Yarn Abrasion (draft) ISO 1704 Shipbuilding, - Stud link anchor chains ISO 2232 Round drawn wire for general purpose non-alloy steel wire ropes and for large diameter steel wire rope- Specifications ISO 3178 Steel wire rope for general purpose - Term of Acceptance ISOITR 13637 Petroleum and natural gas industries - Mooring of mobile offshore drilling unit (MODUS) – Design and Analysis ISO 13819-1: Offshore structure Part 1: General requirements NORSOKM-001 Material selection NORSOK N-003 Action and Action Effects

Design of Offshore Wind Turbine Structures	AISC LRFD Manual of Steel Construction API RP 2A LRFD Planning., Designing and Constructing Fixed Offshore Platform - load and Resistance Factor Design BS 7910 Guide on methods for assessing the acceptability of flaws in fusion welded structures EN10025 Hot rolled products of non-alloy structural steel EN10113 Hot rolled products in weldable fine grain structural steel EN 10204 Metallic structure - types of inspection document:: EN10225 Weldable structural steels for fixed offshore structures - technical delivery condition prEN50308 Wind Turbines - Labour Safety Eurocode 3 Design of Steel Structures IEC61400-1 Wind Turbine Generator Systems - Part 1: Safety Requirements ISO 12944 CSM Paints and varnishes - Corrosion protection of steel structures by protective paint systems; marine, offshore, estuaries, coastal areas with high salinity ISO 14688 Geotechnical investigations and testing - identification and classification of soil - Part 1: Identification and description. ISO / IEC 17020 General criteria for the operation of various types of bodies performing inspections ISO/I EC 17025 General requirements for the competence of calibration and testing laboratories ISO 19900:2002 Petroleum and natural gas industries - Offshore structures - General requirements for offshore structures ISO CD 19001-2 Seismic design procedures and criteria ISO 19902 Petroleum and Natural Gas Industries - Fixed Steel Offshore Structures NORSOK N-003 Actions and Action Effects NORSOK N-004 Design of Steel Structures NORSOK G-CR-001 Marine Soil investigations
Cathodic Protection Design	NACE Standard Recommended Practice RP0176- 83: "' Corrosion Control of Steel Fixed Offshore Platforms Associated with Petroleum Production" NACE Standard Recommended Practice RP0387-87: "Metallurgical and Inspection Requirements for Cast Sacrificial Anodes for Offshore Applications"

	BS 7361 (1 991): "Cathodic Protection Part 1. Code of Practice for Land and Marine Applications" ISO 8501-lISIS 055900-1989: "Pictorial Surface Preparation Standards for Painting Steel Surfaces" U.S. Military Specification MIL-A-1 8001J (1983 + Amendment 1, 1987), Anodes, Corrosion Preventive, Zinc; Slab, Disc: and Rod Shaped"
Fatigue Strength Analysis of Offshore Steel Structures	Classification Note No 30.7 Fatigue Assessment of Ship Structures. Det Norske Veritas 1998. Eurocode : Design of steel structures. Part 1-1: General rules and rules for buildings. February 1993. Guidance on Design, Construction and Certification. HSE. February 1995. BS7910:1999. Guidance on Methods for Assessing the Acceptability of Flaws in Fusion Welded Structures. BSI. Draft 1999.
Design Against Accidental Loads	NORSOK Standard N-003 Action and Action Effect N5-ENV 1993-1 Eurocode 3: Design of Steel structure Part 1-2. General rule - Structural fire design
Design and Installation of Fluke Anchors in Clay	DNV Rule for Classification of Mobile Offshore Units (1996), Position Mooring (PO':MOOR), Pt.6 Ch.2, January 1996. API Recommended Practice 25K (1996), Recommended Practice for Design and Analysis of Station keeping, System for Floating, Structures, r<l Edition, effective from March 1997. Horte, T., Lie, H. and Mathisen, J. (1998), Calibration of an Ultimate limit State for Mooring line, Conference on Offshore Mechanic and Arctic Engineering, (OMAE), Paper 1457. Lisbon. Cramer, E.H., Strom, P.J., Mathisen, J., Ronold, K.O. and Dahlberg, R. (1998), Pilot Reliability Analysis of Fluke Anchor, Joint Industry Project on design procedures for deep water anchors, DNV Report No. 98-3034. Hovi k. Handal, E. and Veland, N. (1998), Determination of tension in anchor lines, 7th European Conference on Non-Destructive Testing, Copenhagen, 26-29 May, 1998. NORS0K standard (1996), Common Requirements Marine Soil investigations, G-CR-001, Rev. 1, dated May 1996.
Design and Installation of Drag-in Plate Anchors in Clay	Dahlberg R., Eklund, T. and Stram, P.J. (1996), *Project Summary· Part 1*, Joint Industry Project on Design procedures for deep water anchors, DNV Report No. 96·3673. Hovik. Dahlberg R, Strom, P.J., Ronold, K.O., Cramer, E. Mathisen, J., Horte, T. and Eklund, T. (1998), *Project Summary· Part Z*, Joint Industry Project on Design procedures for deep water anchor.;, DNV Report No. 98·3591. Holvi k. Dahlberg R., Ronold, K.O., Strom, P.J. and Horte, T. (2002), *Project Summary*, Joint Industry Project on Reliability analysis of deepwater plate anchor.;, DNV Report No. 2002·0282. Hovik. DNV Recommended Practice Rp·E301 (2000), *Design and Installation of fluke Anchors in Clay*, 2000. Hovik. Dahlbera, R. (1998), *Design Procedures for Deepwater Anchors in Clay*, Offshore Technology Conference, Paper OTC 8837, pp. 559-567. Houston.

	Dahlberg R. and Mathisen, J. (2002), *Consistent Design Codes for Anchors and Mooring Lines,* Conference on Offshore Mechanics and Arctic Engineering IOMAE), Paper 28424. Oslo. Offshore Standard, DNV OS·E301 , *Position Mooring.* Havi k. Dahlberg R. and Strom, P.J. (1999), *Unique Onshore tests of Deepwater Drag-in Plate Anchors,* Offshore Technology Conference, Paper OTC 10989. Houston. Heyerdahl, H. and Eklund, T. (2001), *Testing of Plate Anchors,* Offshore Technology Conference, Paper OTC 13273. Houston. NORSOK standard (1996), *Common Requirements Marine Soil Investigation s,* GCR·001, Rev. 1, dated May 1996.
Global Performance Analysis of Deepwater Floating Structures	NORSOK Standard N·003 "Actions and action effects" Arahna, J. A. P. (1996): "'Second order horizontal steady forces and moments on a floating body with small forward speed". J. Fluid Mech. Vol. 313. Engseth , A., Bech, A. and Larsen, C.M. (1988) "Efficient Method for Analysis of Flexible Risers". Proc. BOSS 1988. Faltinsen, O.M. (1 990): "Sea Loads on Ships and Offshore Structures", Cambridge Uni verity Press. Faltinsen, O.M., Ne'NlT1an, J.N., Vinje, T., (1995), Nonlinear wave loads on a slender vertical cylinder, Journal of Fluid Mechanics, Vo l 289, pp. 179·198. Finne, S., Grue, J. and Nestegard, A. (2000) "Prediction of the complete second order wave drift damping force for offshore structures" . 10th ISOPE Conference. Seattle, WA, USA. Isherwood, R.M. (1973) "'Wind resistance on merchant ships:". Trans. Inst. Nav. Arch. (RINA), 115. Karunakaran , D., Nordsve, N.T. and Olufsen, A. (1996) "An Efficient Metal Riser Configuration for Ship and Semi Based Production Systems". Proc. ISOPE 1996, Los Ane,eles. Kim, S., Sclavounos, P.D. and Nielsen, F.G. (1997) "Slow-drift responses of moored platforms". 8t:k Int. BOSS Conference, Delft.
Fatigue Assessment of Ship Structures	Det Norske Veritas, Rules for Classification of Ships, Part 3, Chapter 1, Hull Structural Design, Ships with Length 100 Meters and above, Hovik, January 1993 Hovem, L., Loads and Load Combination:: for Fatigue Calculations - Background for the Wave Load Section for the DNVC Classification Note: Fatigue Assessment of Ships, DNVC Report No. 93-0314, Hovi k, 1993 Cramer, E.H., Loseth, R. and Bitner-Gregesen, E., Fatigue in Side Shell Longitudinals due to External Wave Pressure, Proceedings OMAE conference, Glasgow, June 1993 British Maritime Technology, BMT, (Primary Contributor.: Hogben, H., Da Cunha, L.F. and Oliver, H.N), Global Wave Statistics, Unwin Brothers Limited, London, 1986 Recommendations for the Fatigue Design of Steel Structures, ECCS - Technical Committee 6 – Fatigue, First Edition, 1985

	Maddox, S.J, Fitness for purpose Assessment of Misalignment in Transverse Butt Welds Subject to Fatigue Loading, Welding Institute Report 279, 1985 Almar - Naess, A., Editor, Fatigue Handbook, Tapir, Trondheim 1985 Det Norske Veritas, Classification Note no. 30.6, Structural Reliability Analysis of Marine Structures, Hovik, July 1991 Gran, S, A Course in Ocean Engineering, Developments in for Marine Technology, Vol. 8, Elsevier Science Publisher.: B.V., 1992 Locbers" I. and Unnland, T. : Fatigue Assessment of Floating Production Vessels. Effects of Mean Stress. Stress at Cut-outs. DNV Report No 97-3403. November 1997.

Appendix C. Inspection and Monitoring Checklist: Existing PINC List Review

Operations

PINC No.	Title	Enforcement Action	A	N/A	Notes
G-801	ARE OPERATIONS CONDUCTED IN ACCORDANCE WITH LEASE STIPULATIONS? **Authority:** 30 CFR 250.101	W/C/S	x		A new lease agreement will be required but this PINC will still apply.
G-802	ARE OPERATIONS CONDUCTED IN ACCORDANCE WITH APPROVED APPLICATIONS? **Authority:** 30 CFR 250.410 30 CFR 250.802 30 CFR 250.1202(a)(1) 30 CFR 250.1204(a) 30 CFR 250.513 (a) 30 CFR 250.613 (a) 30 CFR 250.1712	W/C/S	x		The PINC itself is applicable, however, the authority referenced no longer applies and it needs to be changed.
G-803	ARE OPERATIONS CONDUCTED IN ACCORDANCE WITH APPROVED PLANS? **Authority:** 30 CFR 250.200 30 CFR 254.2	W/C/S	x		These CFR sections can apply.

Archaeological

PINC No.	Title	Enforcement Action	A	N/A	Notes
G-808	DOES THE ARCHAEOLOGICAL REPORT SUGGEST THAT ARCHAEOLOGICAL RESOURCES MAY BE PRESENT AND IS THE LOCATION OF THE SITE OF ANY OPERATION LOCATED SO AS TO NOT ADVERSELY AFFECT THE AREA OF THE RESOURCE? **Authority:** 30 CFR 250.194(a)(1) 30 CFR 250.194(c) 30 CFR 250.1010(c)	W/C/S	x		This PINC is relevant, but 30CFR1010 only refers to pipelines and does not address transmission lines
G-809	DOES THE LESSEE'S DISCOVERY OF ANY ARCHAEOLOGICAL RESOURCES IN THE LEASE AREA IMMEDIATELY RESULT IN HALTING OPERATIONS AND TAKING STEPS TO PROTECT SIGNIFICANT RESOURCES AND REPORTING THE DISCOVERY TO THE REGIONAL DIRECTOR? **Authority:** 30 CFR 250.194(a)(1) 30 CFR 250.194(c) 30 CFR 250.1010(c)	W/C/S	x		Same comment as for PINC G-808

Records

PINC No.	Title	Enforcement Action	A	N/A	Notes
G-811	IS REQUIRED PAPERWORK SUBMITTED IN THE TIME FRAME REQUIRED FOR ALL ACTIVITIES OR OPERATIONS AS SPECIFIED BY REGULATIONS? **Authority:** 30 CFR 250.465 30 CFR 250.468 30 CFR 250.513(a) 30 CFR 250.613(a) 30 CFR 250.613(d) 30 CFR 250.1008 30 CFR 250.1202(c)(4) 30 CFR 250.1202(d)(5) 30 CFR 250.1202(f)(2) 30 CFR 250.1203(b)(8) 30 CFR 250.1203(b)(9) 30 CFR 250.1721(g) 30 CFR 251.4 30CFR 251.8(2)	W/C	x		PINC applies, but most of the CFR authority needs to be changed. The only listed CFRs with some relevance are 30 CFR 250.1008 and 30 CFR251.8(2).

PINC No.	Title	Enforcement Action	A	N/A	Notes
	Authority: 30 CFR 250.900(a) 30 CFR 250.900(b)				The CFRs referenced are for oil and gas platforms,but they may have relevance for current and wave, depending on the application
G-822	**DOES THE LESSEE COMPILE, RETAIN, AND MAKE AVAILABLE PLATFORM STRUCTURAL RECORDS FOR THE LIFE OF THE PLATFORM, INCLUDING THE RESULTS OF PLATFORM STRUCTURAL INSPECTIONS?** **Authority:** 30 CFR 250.912 30 CFR 250.914	W	x		PINC and CFRs have relevance, but the inspection requirements will vary based on the structure
G-823	**HAS THE OPERATOR PERFORMED THE REQUIRED STRUCTURAL SURVEYS FOR THE PLATFORM AND SUBMITTED A REPORT OF THE RESULTS ANNUALLY BY NOVEMBER 1 TO THE REGIONAL SUPERVISOR?** **Authority:** 30 CFR 250.912	W	x		see G-822 comment

Bonding

PINC No.	Title	Enforcement Action	A	N/A	Notes
G-831	**DOES THE LESSEE MAINTAIN THE APPROPRIATE BOND REQUIRED?** **Authority:** 30 CFR 256.52 30 CFR 256.53 30 CFR 256.54	W/S	x		PINC would apply depending on MMS policy. 30 CFR 256.54 would apply, but 256.52 and 53 would need to be changed.
G-832	**IF A BOND LAPSES OR DECREASES IN VALUE DURING THE TERM OF THE REQUIRED FINANCIAL COVERAGE, HAS THE LESSEE PROVIDED ACCEPTABLE ALTERNATIVE FINANCIAL COVERAGE TO THE REGIONAL DIRECTOR?** **Authority:** 30 CFR 256.52(e) 30 CFR 256.55 30 CFR 256.56 30 CFR 256.57	W/S	x		CFR references have relevnace,30cfr256.52 (a) has elements that does not apply.
G-833	**HAS THE LESSEE NOTIFIED THE REGIONAL DIRECTOR WITHIN 72 HOURS AFTER LEARNING THAT AN ACTION WAS FILED ALLEGING THAT THE LESSEE, THE SURETY, OR THE GUARANTOR PROVIDING REQUIRED FINANCIAL SECURITY ARE INSOLVENT OR BANKRUPT?** **Authority:** 30 CFR 256.55(b)	W	x		See commentson G-831

Training

PINC No.	Title	Enforcement Action	A	N/A	Notes
G-841	**HAS A WELL-CONTROL AND PRODUCTION SAFETY TRAINING PROGRAM BEEN ESTABLISHED AND IMPLEMENTED?** **Authority:** 30 CFR 250.1503(a)	S		x	Recommend dropping reference to well control,then it could apply The CFR also specifies well control, recommend this could be dropped and then the CFR could have direct relevance.
G-842	**CAN THE LESSEE EXPLAIN ITS OVERALL WELL-CONTROL AND PRODUCTION SAFETY TRAINING PROGRAM AND PRODUCE EVIDENCE TO SUPPORT THE EXPLANATION DURING A TRAINING SYSTEM AUDIT CONDUCTED BY THE MMS OR ITS AUTHORIZED REPRESENTATIVE?** **Authority:** 30 CFR 250.1507(a)	W		x	See comment for PINC G-841
G-843	**DOES THE TRAINING PLAN INCLUDE PROCEDURES FOR TRAINING EMPLOYEES IN WELL-CONTROL OR PRODUCTION SAFETY PRACTICES AND IS THERE EVIDENCE THAT THE PROCEDURES ARE BEING FOLLOWED?** **Authority:** 30 CFR 250.1503(b)(1) 30 CFR 250.1507(a)	W		x	See comment for PINC G-841
G-844	**DOES THE WELL-CONTROL AND PRODUCTION SAFETY TRAINING PLAN SPECIFY THE TYPE, METHOD(S), LENGTH, FREQUENCY, AND CONTENT OF THE TRAINING FOR EMPLOYEES?** **Authority:** 30 CFR 250.1503(b)	W		x	See comment for PINC G-841
G-845	**DOES THE TRAINING PLAN INCLUDE PROCEDURES FOR ASSESSING THE WELL-CONTROL AND PRODUCTION SAFETY TRAINING NEEDS OF EMPLOYEES ON A PERIODIC BASIS AND IS THERE EVIDENCE THAT THE PROCEDURES ARE BEING FOLLOWED?** **Authority:**	W		x	See comment for PINC G-841

PINC No.	Title	Enforcement Action	A	N/A	Notes
	30 CFR 250.1503(b)(4) 30 CFR 250.1507(a)				
G-846	DOES THE TRAINING PLAN INCLUDE PROCEDURES FOR EVALUATING THE WELL-CONTROL AND PRODUCTION SAFETY TRAINING PROGRAMS OF CONTRACTORS AND IS THERE EVIDENCE THAT THE EVALUATIONS ARE BEING CONDUCTED AS PER THE PROCEDURES? **Authority:** 30 CFR 250.1503(b)(2) 30 CFR 250.1507(a)	W		x	See comment for PINC G-841
G-847	DOES THE TRAINING PLAN INCLUDE PROCEDURES FOR INTERNAL AUDITS AND IS THERE EVIDENCE THAT THE INTERNAL AUDITS ARE BEING CONDUCTED AS PER PROCEDURES? **Authority:** 30 CFR 250.1503(b)(6) 30 CFR 250.1507(a)	W	x		This PINC could apply to a Wave and Current Facility.
G-848	DOES THE LESSEE PROVIDE A COPY OF ITS TRAINING PLAN WHEN REQUESTED BY THE MMS REGIONAL OR DISTRICT SUPERVISOR? **Authority:** 30 CFR 250.1503(c)(2)	S	x		PINC applies but CFR specifies well control
G-849	DOES THE WELL-CONTROL AND PRODUCTION SAFETY TRAINING PLAN SPECIFY THE METHOD(S) OF VERIFYING EMPLOYEES' UNDERSTANDING AND PERFORMANCE? **Authority:** 30 CFR 250.1503(b)	W		x	PINC could apply with modification. CFR specifies well control
G-850	ARE PROCEDURES ESTABLISHED TO VERIFY ADEQUATE RETENTION OF THE KNOWLEDGE AND SKILLS THAT EMPLOYEES NEED TO PERFORM THEIR ASSIGNED WELL-CONTROL OR PRODUCTION SAFETY DUTIES AND IS THERE EVIDENCE INDICATING THAT THE KNOWLEDGE AND SKILLS ARE BEING VERIFIED? **Authority:** 30 CFR 250.1506(b) 30 CFR 250.1507(a)	W		x	PINC could be applicable with the exclusion of direct reference to well control. Rather, specify production and maintenance knowledge.
G-851	DOES THE LESSEE ENSURE (EITHER THROUGH THE CONTRACTOR EVALUATION OR OTHER METHOD THAT THE CONTRACTOR'S TRAINING PROGRAM PROVIDE FOR PERIODIC TRAINING AND VERIFICATION OF WELL-CONTROL OR PRODUCTION SAFETY KNOWLEDGE AND SKILLS? **Authority:** 30 CFR 250.1506(c)	W		x	See Comment for PINC G-850
G-852	DOES THE TRAINING PLAN INCLUDE PROCEDURES FOR VERIFYING THAT ALL EMPLOYEES AND CONTRACTOR PERSONNEL ENGAGED IN WELL-CONTROL AND PRODUCTION SAFETY OPERATIONS CAN PERFORM THEIR ASSIGNED DUTIES AND IS THERE EVIDENCE THAT ALL EMPLOYEES AND CONTRACTOR PERSONNEL HAVE BEEN VERIFIED IN ACCORDANCE WITH THE PROCEDURES? **Authority:** 30 CFR 250.1503(b)(3) 30 CFR 250.1507(a)	W		x	See Comment for PINC G-850
G-853	ARE ALTERNATIVE WELL-CONTROL AND PRODUCTION SAFETY TRAINING METHODS CONDUCTED IN ACCORDANCE WITH, AND MEET, THE OBJECTIVES OF THE TRAINING PLAN? **Authority:** 30 CFR 250.1503(a) 30 CFR 250.1504	W		x	See Comment for PINC G-850
G-854	IS WELL-CONTROL AND PRODUCTION SAFETY TRAINING FOR EMPLOYEES PROVIDED FROM SOURCES THAT MEET THE REQUIREMENTS OF THE TRAINING PLAN? **Authority:** 30 CFR 250.1503(a) 30 CFR 250.1505	W		x	See Comment for PINC G-850
G-855	IS PERIODIC TRAINING PROVIDED TO ENSURE THAT EMPLOYEES MAINTAIN UNDERSTANDING OF, AND COMPETENCY IN, WELL-CONTROL OR PRODUCTION SAFETY PRACTICES? **Authority:** 30 CFR 250.1506(a)	W/C		x	See Comment for PINC G-850
G-856	DOES EACH EMPLOYEE UNDERSTAND AND PERFORM THE ASSIGNED WELL-CONTROL OR PRODUCTION SAFETY DUTIES? **Authority:** 30 CFR 250.1503(a)	W/C		x	See Comment for PINC G-850
G-857	DOES THE LESSEE ALLOW MMS OR ITS AUTHORIZED REPRESENTATIVE TO ADMINISTER WRITTEN, ORAL, HANDS-ON WELL-CONTROL OR PRODUCTION SAFETY TESTS AT THE WORK SITE OR ONSHORE LOCATION? **Authority:** 30 CFR 250.1507(c) 30 CFR 250.1508(a)	W		x	See Comment for PINC G-850
G-858	DOES THE LESSEE ALLOW MMS OR ITS AUTHORIZED REPRESENTATIVE TO ADMINISTER OR WITNESS HANDS-ON, SIMULATOR, OR OTHER TYPES OF WELL-CONTROL AND PRODUCTION SAFETY TESTING? **Authority:** 30 CFR 250.1507(d) 30 CFR 250.1509(a)	W		x	See Comment for PINC G-850
G-859	DOES THE LESSEE PAY FOR ALL COSTS ASSOCIATED WITH WELL-CONTROL OR PRODUCTION SAFETY TESTING, EXCLUDING SALARY AND TRAVEL COSTS FOR MMS PERSONNEL? **Authority:** 30 CFR 250.1507(d) 30 CFR 250.1509(c)	W		x	See Comment for PINC G-850
G-860	DOES THE TRAINING PLAN INCLUDE PROCEDURES FOR RECORD KEEPING AND DOCUMENTATION OF WELL-CONTROL AND PRODUCTION SAFETY TRAINING?	W		x	See Comment for PINC G-850

PINC No.	Title	Enforcement Action	A	N/A	Notes
	Authority: 30 CFR 250.1503(b)(5)				
G-861	DOES THE LESSEE IDENTIFY PERSONNEL BY CURRENT POSITION, YEARS OF EXPERIENCE IN PRESENT POSITION, YEARS OF TOTAL OIL FIELD EXPERIENCE, AND EMPLOYER NAME, AT THE WORK SITE OR ONSHORE LOCATION? **Authority:** 30 CFR 250.1508(b) 30 CFR 250.1509(b)	W		x	This specific PINC does not apply, but a similar question could be phrased for offshore electrical production.
G-862	DOES THE LESSEE PROVIDE COPIES OF TRAINING DOCUMENTATION FOR PERSONNEL INVOLVED IN WELL-CONTROL OR PRODUCTION SAFETY OPERATIONS FOR THE PAST FIVE YEARS WHEN REQUESTED BY THE MMS REGIONAL OR DISTRICT SUPERVISOR? **Authority:** 30 CFR 250.1503(c)(1)	W		x	The specific topic of well control does not apply, but confining this PINC to produciton safety operations would make it relevant.

Production Reporting

PINC No.	Title	Enforcement Action	A	N/A	Notes
G-881	HAS THE OPERATOR SUBMITTED A REPORT TO THE DISTRICT SUPERVISOR OF INITIAL PRODUCTION FROM A LEASE? **Authority:** 30 CFR 250.180(a)(1) 30 CFR 250.180(i)(1)	W	x		This PINC could apply if the referenced CFR was changed such that the definition of operations covered renewable energy production and not well drilling and oil/gas production.
G-882	HAS THE OPERATOR SUBMITTED A REPORT TO THE DISTRICT SUPERVISOR OF CESSATION OF PRODUCTION ON A LEASE? **Authority:** 30 CFR 250.180(a)(1) 30 CFR 250.180(i)(2)	W	x		See comment for PINC G-881

Accident Reporting

PINC No.	Title	Enforcement Action	A	N/A	Notes
G-891	HAS THE DISTRICT MANAGER BEEN NOTIFIED WITH A WRITTEN REPORT WITHIN 15 DAYS OF THE INCIDENT INVOLVING ALL: FATALITIES, INJURIES INVOLVING LOST TIME AND EVACUATION, LOSS OF WELL CONTROL, FIRES, EXPLOSIONS, H2S RELEASES AS DEFINED BY 30 CFR 250.490(1), COLLISIONS, STRUCTURAL DAMAGES, CRANE INCIDENTS, SAFETY SYSTEM DAMAGES, GAS RELEASES THAT INITIATE EQUIPMENT OR PROCESS SHUTDOWN, ALL INCIDENTS THAT RESULT IN DAMAGES GREATER THAT $25,000, AND ALL INCIDENTS THAT REQUIRE PERSONNEL TO MUSTER FOR EVACUATION? **Authority:** 30 CFR 250.187 30 CFR 250.188 30 CFR 250.190 30 CFR 250.191 30 CFR 250.490	W		x	Could apply with modification by removing reference to H2S and gas release. CFR would have to be changed to support this.
G-892	HAS THE DISTRICT MANGER BEEN VERBALLY NOTIFIED COMMUNICATION IMMEDIATELY FOLLOWING INCIDENTS INVOLVING ALL: FATALITIES, INJURIES REQUIRING EVACUATION, LOSS OF WELL CONTROL, FIRES, EXPLOSIONS,H2S RELEASES AS DEFINED IN 30 CFR 250.490(1), COLLISIONS, STRUCTURAL DAMAGES, CRANE INCIDENTS AND SAFETY SYSTEM DAMAGES CONNECTED WITH ANY OPERATIONS OR ACTIVITIES ON A LEASE, RIGHT-OF-USE AND EASEMENT, PIPELINE RIGHT-OF-WAY, OR OTHER PERMIT ISSUED BY MMS? **Authority:** 30 CFR 250.187 30 CFR 250.188 30 CFR 250.189 30 CFR 250.191 30 CFR 250.490	W		x	See Comment G-891

ENVIRONMENTAL PROTECTION

OIL SPILL RESPONSE PLANS

PINC No.	Title	Enforcement Action	A	N/A	Notes
E-801	IS THE FACILITY OR PIPELINE COVERED BY AN APPROVED OIL SPILL RESPONSE PLAN OR A CERTIFICATION OF CAPABILITY TO RESPOND TO A WORST CASE DISCHARGE? **Authority:** 254.1(a) 254.2(a) 254.2(b)	***	x		Worst case oil spills would be on a much smaller scale, and may not be applicable for some of the technologies to be potentially deployed. Reference CFRs need to be changed.

PINC No.	Title	Enforcement Action	A	N/A	Notes
E-802	HAS THE REGIONAL SUPERVISOR BEEN NOTIFIED OF RESULTS OF AN OIL SPILL PLAN REVIEW AND/OR RECEIVED REQUIRED REVISIONS TO THE OIL SPILL RESPONSE PLAN? **Authority:** 254.2(a) 254.30(a) 254.30(b) 254.30(c) 254.30(d) 254.30(e)	W/S	x		See Comment E-802

TRAINING

PINC No.	Title	Enforcement Action	A	N/A	Notes
E-821	HAS THE SPILL RESPONSE OPERATING TEAM COMPLETED REQUIRED TRAINING, AND ARE RECORDS BEING MAINTAINED? **Authority:** 254.2(a) 254.5(a) 254.40 254.41(a) 254.41(d) 254.42(e)	W/S	x		Could apply to some wave and current technologies unless waivers were granted. CFRs would need to be changed.
E-822	HAS THE SPILL MANAGEMENT TEAM COMPLETED REQUIRED TRAINING, AND ARE RECORDS BEING MAINTAINED? **Authority:** 254.2(a) 254.5(a) 254.40 254.41(b) 254.41(c) 254.41(d) 254.42(e)	W/S			See comment E-821

EXERCISES

PINC No.	Title	Enforcement Action	A	N/A	Notes
E-831	WAS THE REGIONAL SUPERVISOR INFORMED 30 DAYS IN ADVANCE OF THE DATE OF THE SCHEDULED THE EXERCISE? **Authority:** 254.2(a) 254.5(a) 254.42(f)	W/S	x		Unless waivers were granted for some technologies
E-832	ARE EXERCISES FOR ALL PARTS OF THE OIL SPILL RESPONSE PLAN CONDUCTED AT LEAST ONCE EVERY THREE YEARS, AND ARE RECORDS BEING MAINTAINED? **Authority:** 254.2(a) 254.5(a) 254.40 254.42(a) 254.42(b) 254.42(c) 254.42(d) 254.42(e)	W/S	x		Unless waivers were granted for some technologies
E-833	DURING AN UNANNOUNCED OIL SPILL DRILL, DID THE OPERATOR SUCCESSFULLY DEMONSTRATE THE ABILITY TO IMMEDIATELY CARRY OUT PROVISIONS OF THE APPROVED OIL SPILL RESPONSE PLAN? **Authority:** 250.132(a) 250.132(b) 254.2(a) 254.41(a) 254.41(b) 254.41(c) 254.41(d) 254.42(g) 254.42(h)	W/S	x		Unless waivers were granted for some technologies
E-841	ARE OBSERVED OIL DISCHARGES REPORTED BY THE OPERATOR? **Authority:** 254.2(a) 254.46(a) 254.46(b) 254.46(c)	W/S	x		
E-842	DURING AND FOLLOWING AN OIL DISCHARGE FROM A FACILITY AND/OR PIPELINE,WERE IMMEDIATE RESPONSE ACTIONS TAKEN AND WERE THEY CONSISTENT WITH THE APPROVED OIL SPILL RESPONSE PLAN? **Authority:**	W/S	x		

PINC No.	Title	Enforcement Action	A	N/A	Notes
	250.132(a) 250.132(b) 250.107(b) 250.300(a)(1) 254.2(a) 254.5(a) 254.5(c) 254.23(a) 254.23(b) 254.23(c) 254.23(d) 254.23(e) 254.23(f) 254.23(g) 254.40				

DRILLING

PLAN APPROVAL

PINC No.	Title	Enforcement Action	A	N/A	Notes
D-801	**HAS WRITTEN APPROVAL TO DRILL, SIDETRACK, BYPASS, OR DEEPEN A WELL BEEN RECEIVED?** **Authority:** 30 CFR 250.410	C		x	
D-802	**DOES THE LESSEE HAVE WRITTEN OR ORAL APPROVAL TO CHANGE PLANS, MAKE CHANGES IN MAJOR DRILLING EQUIPMENT OR PLUG BACK A WELL?** **Authority:** 30 CFR 250.465(a)(1)	C		x	
D-803	**IS THE DISTRICT SUPERVISOR GIVEN AT LEAST 24 HOURS NOTICE BEFORE STARTING A WELL TEST?** **Authority:** 30 CFR 250.460(b)	W		x	

CASING PROGRAM

PINC No.	Title	Enforcement Action	A	N/A	Notes
D-821	**IS CASING SET AS APPROVED?** **Authority:** 30 CFR 250.420	W		x	
D-822	**IF THE CASING SETTING DEPTHS ARE MORE THAN 100 FEET TVD FROM THE APPROVED APD, HAS THE CHANGE BEEN APPROVED?** **Authority:** 30 CFR 250.428(b)	W		x	

WELL CONTROL

PINC No.	Title	Enforcement Action	A	N/A	Notes
D-831	**ARE DRILLING OPERATIONS SUSPENDED WHEN THE SAFE MARGIN, AS APPROVED IN THE APD, BETWEEN THE DRILLING FLUID WEIGHT IN USE AND THE EQUIVALENT DRILLING FLUID WEIGHT AT THE CASING SHOE IS NOT MAINTAINED?** **Authority:** 30 CFR 250.427(b)	W		x	

RIG MOVEMENT

PINC No.	Title	Enforcement Action	A	N/A	Notes
D-841	**IS THE MOVEMENT OF ALL DRILLING UNITS ON AND OFF LOCATION REPORTED TO THE DISTRICT SUPERVISOR 24 HOURS PRIOR TO THE MOVEMENT, INCLUDING THE RIG NAME, LEASE NUMBER, WELL NUMBER, AND THE EXPECTED TIME OF ARRIVAL OR DEPARTURE?** **Authority:** 30 CFR 250.403(a) 30 CFR 250.403(b)	W		x	

WELL-COMPLETIONS

PINC No.	Title	Enforcement Action	A	N/A	Notes
C-801	**HAS THE LESSEE RECEIVED WRITTEN APPROVAL FROM THE DISTRICT SUPERVISOR PRIOR TO CONDUCTING WELL-COMPLETION OPERATIONS?** **Authority:** 30 CFR 250.505 30 CFR 250.513(a)	C		x	

WELL-WORKOVERS

PINC No.	Title	Enforcement Action	A	N/A	Notes
W-801	**HAS THE LESSEE RECEIVED WRITTEN APPROVAL FROM THE DISTRICT SUPERVISOR PRIOR TO CONDUCTING NON-ROUTINE WELL-WORKOVER OPERATIONS?** **Authority:** 30 CFR 250.601 30 CFR 250.605 30 CFR 250.613(a)	C		x	

DECOMMISSIONING

PINC No.	Title	Enforcement Action	A	N/A	Notes
A-801	**IS ISOLATION OF ZONES IN OPEN HOLE ACHIEVED?**	W			

PINC No.	Title	Enforcement Action	A	N/A	Notes
	Authority: 30 CFR 250.1715(a)(1)			x	

PRODUCTION

PINC No.	Title	Enforcement Action	A	N/A	Notes
P-801	HAS APPROVAL BEEN RECEIVED WHEN THE OPERATOR HAS FLARED OR VENTED OIL-WELL GAS IN EXCESS OF 48 CONTINUOUS HOURS OR 144 CUMULATIVE HOURS DURING ANY MONTH? **Authority:** 30 CFR 250.1105(a)(2)(i) 30 CFR 250.1105(a)(2)(ii)	W/C		x	

PIPELINES

INSTALLATION/RELOCATION

PINC No.	Title	Enforcement Action	A	N/A	Notes
L-801	HAS THE REGIONAL SUPERVISOR BEEN NOTIFIED PRIOR TO THE COMMENCEMENT OF THE INSTALLATION OR RELOCATION OF A PIPELINE? **Authority:** 30 CFR 250.1008(a)	W/C		x	Could apply if changes were made to reference transmission lines. Pipelines for non-petroleum products could be installed with some technologies.
L-802	WAS THE PIPELINE CONSTRUCTED IN A MANNER TO MINIMIZE DEVIATION FROM THE ROW GRANTED? **Authority:** 30 CFR 250.1012(b)(1) 30 CFR 250.1012(b)(3)	W/C		x	See Comment L-801
L-803	HAS THE LESSEE OR THE ROW HOLDER SUBMITTED A COMPLETION REPORT TO THE REGIONAL SUPERVISOR AFTER COMPLETION OF ANY PIPELINE CONSTRUCTION? **Authority:** 30 CFR 250.1008(b)	W/C		x	See Comment L-801
L-804	IS THE PIPELINE PROPERLY MAINTAINED AND USED FOR THE PURPOSE FOR WHICH THE ROW WAS GRANTED? **Authority:** 30 CFR 250.1009(e)	W/C		x	See Comment L-801

TESTING

PINC No.	Title	Enforcement Action	A	N/A	Notes
L-811	HAS THE REGIONAL SUPERVISOR BEEN NOTIFIED PRIOR TO A PRESSURE TEST ON A PIPELINE? **Authority:** 30 CFR 250.1008(a)	W/C		x	See comment L-801, Other test may apply for transmission lines-insulation tests, high potential tests, etc.
L-812	HAVE THE RESULTS AND CONCLUSIONS OF MEASUREMENTS OF PIPE-TO-ELECTROLYTE POTENTIAL MEASUREMENTS TAKEN ANNUALLY ON EACH DOI PIPELINE BEEN SUBMITTED TO THE REGIONAL SUPERVISOR? **Authority:** 30 CFR 250.1000(e)(1) 30 CFR 250.1005(b) 30 CFR 250.1008(h)	C		x	
L-813	HAVE PIPELINES THAT WERE INSTALLED, RELOCATED, UPRATED, OR REACTIVATED AFTER BEING OUT OF SERVICE FOR MORE THAN 1 YEAR, BEEN HYDROSTATICALLY TESTED WITH WATER TO A STABILIZED PRESSURE OF AT LEAST 1.25 TIMES THE MAOP FOR AT LEAST 8 HOURS? **Authority:** 30 CFR 250.1003(b)(1) 30 CFR 250.1003(b)(3)	W/C		x	See Comment L-811

OUT-OF-SERVICE REPORTING

PINC No.	Title	Enforcement Action	A	N/A	Notes
L-821	HAS THE LESSEE OR THE ROW HOLDER REPORTED A PIPELINE TAKEN OUT OF SERVICE TO THE REGIONAL SUPERVISOR? **Authority:** 30 CFR 250.1008[C]	W		x	See Comment L-811
L-822	HAS THE LESSEE OR THE ROW HOLDER REPORTED ANY PIPELINE SAFETY EQUIPMENT TAKEN OUT OF SERVICE FOR MORE THAN 12 HOURS TO THE REGIONAL SUPERVISOR? **Authority:** 30 CFR 250.1000(e)(1) 30 CFR 250.1008(d)	W/C		x	See Comment L-811
L-823	HAS THE REGIONAL SUPERVISOR BEEN NOTIFIED WHEN THE PIPELINE SAFETY EQUIPMENT IS RETURNED TO SERVICE? **Authority:** 30 CFR 250.1008(d)	W		x	See Comment L-811

REPAIR

PINC No.	Title	Enforcement Action	A	N/A	Notes

PINC No.	Title	Enforcement Action	A	N/A	Notes
L-831	HAS THE LESSEE OR THE ROW HOLDER NOTIFIED THE REGIONAL SUPERVISOR PRIOR TO THE REPAIR OF A PIPELINE OR AS SOON AS PRACTICABLE THEREAFTER? **Authority:** 30 CFR 250.1008(e)	W		x	See Comment L-811
L-832	HAS A DETAILED REPORT ON THE REPAIR OF A PIPELINE OR PIPELINE COMPONENT BEEN SUBMITTED TO THE REGIONAL SUPERVISOR? **Authority:** 30 CFR 250.1000(e)(1) 30 CFR 250.1008(e)	W/C		x	See Comment L-811
L-833	HAS THE LESSEE SUBMITTED TO THE REGIONAL SUPERVISOR A COMPREHENSIVE WRITTEN REPORT OF ANY PIPELINE FAILURE ANALYZED? **Authority:** 30 CFR 250.1008(f)	W		x	See Comment L-811
L-834	HAS A PLAN OF CORRECTIVE ACTION FOR OBSERVED DETRIMENTAL ENVIRONMENTAL FACTORS AFFECTING A PIPELINE BEEN SUBMITTED TO THE REGIONAL SUPERVISOR FOR APPROVAL? **Authority:** 30 CFR 250.1000(e)(1) 30 CFR 250.1008(g)	W/C		x	See Comment L-811
L-835	HAS A REPORT OF REMEDIAL ACTION TAKEN FOR DETRIMENTAL ENVIRONMENTAL FACTORS AFFECTING A PIPELINE BEEN SUBMITTED TO THE REGIONAL SUPERVISOR BY THE LESSEE OR ROW HOLDER? **Authority:** 30 CFR 250.1000(e)(1) 30 CFR 250.1008(g)	W/C		x	See Comment L-811

DECOMMISSIONING

PINC No.	Title	Enforcement Action	A	N/A	Notes
L-841	ARE PIPELINES OUT OF SERVICE FOR 5 YEARS, OR MORE, REMOVED IF THE PIPELINES ARE DETERMINED BY THE REGIONAL SUPERVISOR TO BE OBSTRUCTIONS? **Authority:** 30 CFR 250.1006(b)(3) 30 CFR 250.1752 30 CFR 250.1754	W		x	

COMPANY INFORMATION

PINC No.	Title	Enforcement Action	A	N/A	Notes
L-851	HAS THE ROW HOLDER KEPT THE REGIONAL SUPERVISOR INFORMED OF THE COMPANY'S OFFICE ADDRESS, AND THE NAME AND ADDRESS OF OFFICER OR AGENT AUTHORIZED TO BE SERVED WITH PROCESS? **Authority:** 30 CFR 250.1009(c)(5)	W	x		This could apply in the case of transmission lines

CONSERVATION OF RESOURCES

INTERESTS

PINC No.	Title	Enforcement Action	A	N/A	Notes
R-801	COMMENCE PRODUCTION FROM A WELL COMPLETION THAT IS WITHIN 500 FEET FROM A UNIT OR LEASE LINE FOR WHICH THE UNIT, LEASE, OR ROYALTY INTERESTS ARE NOT THE SAME? **Authority:** 30 CFR 250.1101(b)	C		x	
R-802	HAS THE OPERATOR RECEIVED APPROVAL FROM THE REGIONAL SUPERVISOR BEFORE COMPLETING AN INTERVAL WHICH ENCOMPASSES MULTIPLE RESERVOIRS THAT ARE COMMINGLED WITHIN THE WELLBORE? **Authority:** 30 CFR 250.1106(a) 30 CFR 250.1106(b)	W/C		x	
R-803	HAS THE OPERATOR OBTAINED AN APPROVED CONSERVATION INFORMATION DOCUMENT (CID) PRIOR TO COMMENCING PRODUCTION OF A DEEPWATER DEVELOPMENT LOCATED IN WATER DEPTHS GREATER THAN 400 METERS (1312 FEET)? **Authority:** 296(a) 299	W	x		
R-804	HAS THE OPERATOR SUBMITTED A REVISION TO THEIR APPROVED CONSERVATION INFORMATION DOCUMENT (CID) AND RECEIVED APPROVAL OF THIS REVISION BEFORE BYPASSING A RESERVOIR REQUIRED BY DEVELOPMENT IN THE ORIGINAL CID? **Authority:** 296(b)	W		x	

ENHANCED RECOVERY

PINC No.	Title	Enforcement Action	A	N/A	Notes
R-811	HAS THE LESSEE RECEIVED APPROVAL FROM THE REGIONAL SUPERVISOR PRIOR TO INITIATING AN ENHANCED OIL AND GAS RECOVERY PROJECT OR OTHER TYPE OF INJECTION PROJECT? **Authority:** 30 CFR 250.1107(b)	W		x	
R-812	HAS THE LESSEE INITIATED ENHANCED OIL AND GAS RECOVERY OPERATIONS IN A TIMELY MANNER FOR COMPETITIVE AND NONCOMPETITIVE RESERVOIRS? **Authority:** 30 CFR 250.1107(a) 30 CFR 250.118 30 CFR 251.4 30CFR 251.8(2)	W		x	

PINC No.	Title	Enforcement Action	A	N/A	Notes
R-813	ARE REPORTS OF THE VOLUMES OF OIL, GAS, AND OTHER SUBSTANCES INJECTED INTO, PRODUCED FROM, OR REPRODUCED FROM A RESERVOIR SUBMITTED TO THE REGIONAL SUPERVISOR WHEN REQUESTED? **Authority:** 30 CFR 250.1107(c) 30 CFR 251.4 30 CFR 251.8(2) 30 CFR 250.118	W		x	

PRODUCTION RATE

PINC No.	Title	Enforcement Action	A	N/A	Notes
R-821	HAS THE LESSEE CONDUCTED A WELL-FLOW POTENTIAL TEST WITHIN 30 DAYS AFTER THE DATE OF FIRST CONTINUOUS PRODUCTION ON A NEW, RECOMPLETED, OR REWORKED WELL COMPLETION? **Authority:** 30 CFR 250.1102(b)(2)	W		x	
R-822	HAS THE LESSEE SUBMITTED, FOR APPROVAL BY THE REGIONAL SUPERVISOR, A PROPOSED MPR WITH THE WELL-FLOW POTENTIAL TEST DATA, ON FORM MMS-126, WELL POTENTIAL TEST REPORT, WITHIN 15 CALENDAR DAYS AFTER THE END OF THE TEST PERIOD? **Authority:** 30 CFR 250.1102(b)(2)	W		x	
R-823	ARE THE WELLS AND RESERVOIRS BEING PRODUCED AT RATES THAT WILL DEPLETE THE HYDROCARBON RESOURCES IN A MANNER THAT MAXIMIZES ULTIMATE RECOVERY WITHOUT ADVERSELY AFFECTING CORRELATIVE RIGHTS? **Authority:** 30 CFR 250.1101(a)	W		x	

WELL TESTS

PINC No.	Title	Enforcement Action	A	N/A	Notes
R-831	HAS THE LESSEE CONDUCTED AT LEAST ONE WELL TEST FOR PRODUCING OIL-WELL OR GAS-WELL COMPLETIONS, DURING A HALF-CALENDAR YEAR? **Authority:** 30 CFR 250.1102(b)(3)	W		x	
R-832	HAS THE LESSEE SUBMITTED WELL TEST RESULTS FOR EACH PRODUCING OIL-WELL AND GAS-WELL COMPLETION TO THE REGIONAL SUPERVISOR ON FORM MMS-128, SEMIANNUAL WELL TEST REPORT, WITHIN 45 DAYS AFTER THE TEST WAS CONDUCTED? **Authority:** 30 CFR 250.1102(b)(3)	W		x	
R-833	HAS THE OPERATOR SUBMITTED A REQUEST FOR A SUSPENSION BEFORE THE END OF THE LEASE TERM, END OF THE 180-DAY PERIOD FOLLOWING THE LAST LEASE HOLDING ACTIVITY, OR END OF A CURRENT SUSPENSION? **Authority:** 30 CFR 250.171	W		x	

PRODUCTION MEASUREMENT AND SITE SECURITY

CALIBRATION

PINC No.	Title	Enforcement Action	A	N/A	Notes
M-801	IS EACH MECHANICAL DISPLACEMENT PROVER AND TANK PROVER CALIBRATED AT LEAST ONCE EVERY 5 YEARS AND A COPY OF THE CALIBRATION REPORT SUBMITTED TO THE REGIONAL SUPERVISOR? **Authority:** 30 CFR 250.1202(f)	W		x	
M-802	IS EACH OPERATING ROYALTY METER PROVED MONTHLY TO DETERMINE THE METER FACTOR AND IS THE PROVING REPORT SUBMITTED TO THE REGIONAL SUPERVISOR? **Authority:** 30 CFR 250.1202(d)(3) 30 CFR 250.1202(d)(4) 30 CFR 250.1202(d)(5)	W/C		x	A derivation of this PINC could apply relevant to energy production
M-803	IS THE RUN TICKET FOR EACH ROYALTY METER AND ROYALTY TANK COMPLETE, WAS IT PULLED WHEN REQUIRED, AND WAS IT SUBMITTED TO THE REGIONAL SUPERVISOR? **Authority:** 30 CFR 250.1202(c)	W/C		x	

LIQUID ROYALTY METER

PINC No.	Title	Enforcement Action	A	N/A	Notes
M-821	ARE LIQUID HYDROCARBON ROYALTY METERS TAKEN OUT OF SERVICE, REPAIRED OR REPLACED, AND REPROVEN IF THE DIFFERENCE BETWEEN THE METER FACTOR AND THE PREVIOUS METER FACTOR EXCEEDS 0.0025? **Authority:** 30 CFR 250.1202(i)(1)	W		x	See Comment M-802

GAS ROYALTY METER

PINC No.	Title	Enforcement Action	A	N/A	Notes
M-831	ARE GAS VOLUME AND QUALITY STATEMENT DISPOSITIONS ON GAS ROYALTY METERS SUBMITTED TO THE REGIONAL SUPERVISOR WHEN REQUESTED? **Authority:** 30 CFR 250.1203(b)(6) 30 CFR 250.1203(b)(7) 30 CFR 250.1203(b)(8) 30 CFR 250.1203(b)(9)	W/C		x	See Comment M-802

GEOLOGICAL AND GEOPHYSICAL EXPLORATION

PERMITS

PINC No.	Title	Enforcement Action	A	N/A	Notes
O-801	**IS REQUIRED PERMIT APPROVED OR NOTICE OF SCIENTIFIC RESEARCH FILED PRIOR TO CONDUCTING A GEOLOGICAL OR GEOPHYSICAL ACTIVITY?** **Authority:** 30 CFR 251.1 30 CFR 251.3 30 CFR 251.4 30 CFR 251.5 30 CFR 251.10	S	x		
O-802	**ARE GEOLOGICAL AND GEOPHYSICAL ACTIVITIES BEING CONDUCTED IN ACCORDANCE WITH REGULATIONS AND AN APPROVED PERMIT?** **Authority:** 30 CFR 251.1 30 CFR 251.3 30 CFR 251.4 30 CFR 251.6 30 CFR 251.7 30 CFR 251.8 30 CFR 251.9 30 CFR 251.10	W/S	x		

DATA

PINC No.	Title	Enforcement Action	A	N/A	Notes
O-811	**ARE REQUIRED GEOLOGICAL AND GEOPHYSICAL DATA AND INFORMATION SUBMITTED TO MMS WITHIN THE TIME FRAME SPECIFIED BY REGULATION AND PERMIT?** **Authority:** 30 CFR 251.1 30 CFR 251.10 30 CFR 251.11 30 CFR 251.12	W	x		

Appendix D. Selected Wave and Current Energy Device Developers

Company	Wave [W] Current [C]	Type	Origin	URL
Able Technologies, LLC	W	Point Absorber	USA	http://www.abletechnologiesllc.com/
AER NY-Kinetics, LLC		FERC	USA	none
Alaska Power & Telephone Company		FERC	USA	http://www.aptalaska.com
American Hydro Energy Company	W / C	H-Axis Turbine	USA	http://wrgl.net/american%20hydro.html
Applied Technologies Company Ltd	W	Attenuator	Russia	http://www.atecom.ru/wave-energy/
Aqua Energy / Finevara Renewables	W	Attenuator	USA	http://www.finavera.com/
Aquamarine Power	W / C	H-Axis Turbine / PSHS	UK	http://www.aquamarinepower.com
Aquantis Technologies	C	H-Axis Turbine	USA	http://www.aquantistech.com/
Aquaphile sarl (Hydro-Gen)	C	Other	France	http://www.hydro-gen.fr
Atlantis Resources Corporation	C	H-Axis Turbine	Australia	http://www.atlantisresourcescorporation.com/
Atmocean, Inc.	W	Upwelling devices	USA	http://www.atmocean.com/
AW Energy	W	PSHS	Finland	http://www.aw-energy.com/
AWS Ocean Energy (formerly Oceanerg	W	Pressure Differential	UK	http://www.awsocean.com
BioPower Systems Pty Ltd	W / C	Wave Surge	Australia	http://www.biopowersystems.com/
Blue Energy	C	V-Axis Turbine	Canada	http://www.bluenergy.com
Bourne Energy	W	H-Axis Turbine	USA	http://www.bourneenergy.com/
Brandl Motor	W	Attenuator	Germany	http://brandlmotor.de/index_eng.htm
Caley Ocean Systems	W / C	Marine Engineering	UK	http://www.caley.co.uk/os/index.htm
Ceto Wave Energy	W	Point Absorber	Australia	http://www.ceto.com.au/home.php
Checkmate Seaenergy UK Ltd.	W	Other	UK	http://www.checkmateuk.com/seaenergy/
Chevron Technology Ventures LLC		FERC	USA	http://www.chevron.com/ctv/
City of Tacoma		FERC	USA	http://www.cityoftacoma.org
Clean Current Power Systems	C	H-Axis Turbine	Canada	http://www.cleancurrent.com
College of the North Atlantic	W	Point Absorber	Canada	http://www.cna.nl.ca
Columbia Power Technologies	W	Point Absorber	USA	http://www.columbiapwr.com/
Current Power AB	C	V-Axis Turbine	Sweden	http://www.currentpower.se/
C-Wave	W	Other	UK	http://www.cwavepower.com/
Daedalus Informatics Ltd.	C	PSHS	Greece	http://www.daedalus.gr
DEXA Wave UK Ltd	W	Other	USA	http://www.dexawaveenergy.co.uk/
Douglas County		FERC	USA	http://www.co.douglas.or.us/
E.ON	W	Other	UK	http://www.eon-uk.com/generation/wave.aspx
Ecofys (Subsidiary of Econcern)	W / C	V-Axis Turbine	Netherlands	http://www.c-energy.nl
Ecole Centrale de Nantes	W	Attenuator	France	http://www.ec-nantes.com
Edinburgh University (aka Wave Power	W	Attenuator	UK	http://www.mech.ed.ac.uk/research/wavepower
Embley Energy	W	OWC	UK	http://www.sperboy.com/
Endinburgh Designs	W	Point Absorber	UK	www.edesign.co.uk
Fieldstone Energy, Inc.	C	Other	USA	http://fieldstoneenergy.com/
Finavera	W	Point Absorber	Canada	http://www.finavera.com
Float Inc.	W	OWC	USA	http://www.floatinc.com
Floating Power Plant ApS (F.P.P.)	W / C	PSHS	Denmark	http://www.poseidonorgan.com
Floating Wave Powered Generator	W	Other	USA	http://www.gedwardcook.com/wave.html
Fobox AS	W	Point Absorber	Norway	none
Free Flow 69	C	H-Axis Turbine	UK	http://www.freeflow69.com
Free Flow Power Corporation	C	H-Axis Turbine	USA	http://www.free-flow-power.com/
G Edward Cook	W	Attenuator, OWC	USA	http://www.gedwardcook.com/wave.html
GCK Technology	C	V-Axis Turbine	USA	http://www.gcktechnology.com
Grays Harbor Ocean Energy Co.		FERC	USA	http://graysharboroceanenergy.com/
Green Ocean Energy Ltd.	W	Attenuator	UK	http://www.greenoceanenergy.com
Greencat Renewables	W	Other	UK	http://www.greencatrenewables.co.uk/waveenergy.html
Greenheat Systems Limited	W / C	Overtopping	UK	http://www.greenheating.com/
GyroWaveGen	W	Other	USA	http://peswiki.com/index.php/Directory:GyroWaveGen(tm)
Hammerfest Strom UK (StatoilHydro)	C	H-Axis Turbine	UK	http://www.hammerfeststrom.com
Hidroflot S.L.	W	Point Absorber	Spain	http://www.hidroflot.com/
Hydam Technology	W	Attenuator	Ireland	McCabe Wave Pump (MWP)
Hydro Green Energy	C	H-Axis Turbine	USA	http://www.hgenergy.com
HydroCoil Power, Inc.	C	H-Axis Turbine	USA	http://www.hydrocoilpower.com
Hydrohelix Energies	C	H-Axis Turbine	France	www.hydrohelix.fr
Hydroventuri	C	Venturi Effect	UK	http://www.hydroventuri.com/news.php
Hyper Drive Ltd.	W	Point Absorber	USA	http://www.hyperdrive-web.com/P1ENindex.html
Independent Natural Resources	W	Attenuator	USA	http://www.inri.us/
Indian Wave Energy Device	W	Attenuator	India	http://waveenergy.nualgi.com/
Ing Arvid Nesheim	W / C	Attenuator	Norway	http://www.anwsite.com/
Instituto Superior Tecnico	W	OWC	Portugal	http://www.pico-owc.net/
Interproject Service (IPS) AB	W	Attenuator	Sweden	Interproject Service (IPS) AB
JAMSTEC	W	Overtopping	Japan	JAMSTEC
Kinetic Energy Systems	C	H-Axis Turbine	USA	www.kineticenergysystems.com
Kinetic Wave Power	W	Other	USA	http://www.kineticwavepower.com
Lancaster University	W	Point Absorber	UK	http://www.engineering.lancs.ac.uk/lureg/research/Wave%20energy.asp
Langlee Wave Power AS	W	PSHS	Norway	http://www.langlee.no
Leancon Wave Energy	W	OWC	Denmark	http://www.leancon.com
Leviathan Marine Development	W / C	Other	Israel	http://www.leviathanenergy.com
Lucid Energy Technologies LLC (GCK)	C	V-Axis Turbine	USA	http://www.lucidenergy.com
Lunar Energy	C	H-Axis Turbine	UK	http://www.lunarenergy.co.uk
Maine Maritime Academy	W / C	Test Facility	USA	http://www.mainemaritime.edu/
Mananook Associates		FERC	USA	none
Manchester Bobber	W	Attenuator	UK	http://www.manchesterbobber.com/index.htm

Company	Wave [W] Current [C]	Type	Origin	URL
Marine Current Turbines	C	H-Axis Turbine	UK	http://www.marineturbines.com
MARMC Enterprises, LLC		FERC	USA	none
Martifer Energia	W	Attenuator	Portugal	http://www.martifer.com/Construction/EN/EnergyEquipments/Wave/Wave.html
Motor Wave Group	W	Point Absorber	China	http://www.motorwavegroup.com
Muroran Institute of Technology	W	Oscillating Wave Surge	Japan	http://www.muroran-it.ac.jp/index-e.html
Natural Currents Energy Services	C	H-Axis Turbine	USA	http://www.naturalcurrents.com
Neo-Aerodynamic Ltd Company	C	V-Axis Turbine	USA	http://www.neo-aerodynamic.com/
Neptune Renewable Energy Ltd	W / C	Multiple	UK	http://www.neptunerenewableenergy.com/index.php
New Energy Corp.	C	V-Axis Turbine	Canada	http://www.newenergycorp.ca/index.htm
Norwegian University of Sci. & Tech	W	Point Absorber	Norway	http://www.ntnu.no/energy/cre
Ocean Energy	W	OWC	Ireland	http://www.oceanenergy.ie
Ocean Flow Energy	C	H-Axis Turbine	UK	http://www.oceanflowenergy.com
Ocean Motion International	W	Point Absorber	USA	http://www.oceanmotion.ws/
Ocean Navitas	W	Attenuator	UK	http://www.oceannavitas.com/
Ocean Power Technologies, Inc.	W	Point Absorber	USA	http://www.oceanpowertechnologies.com
Ocean Renewable Power Co.	C	H-Axis Turbine	USA	www.oceanrenewablepower.com
Ocean Wave Energy Company	W	Point Absorber	USA	http://www.owec.com
Oceana Energy Company	C	H-Axis Turbine	USA	http://www.oceanaenergy.com
Oceanlinx (formerly Energetech)	W	OWC	Australia	http://www.oceanlinx.com/
Offshore Islands Limited	W / C	Multiple	USA	http://www.offshoreislandslimited.com/
Offshore Wave Energy Ltd	W	OWC	UK	http://www.owel.co.uk/print/welcome.htm
Openhydro	C	H-Axis Turbine	Ireland	http://www.openhydro.com
ORECon	W	OWC	UK	http://www.orecon.com/
Oregon State University (OSU)	W / C	Multiple	USA	http://eecs.oregonstate.edu/wesrf/
Overberg Limited	W	Multiple	UK	http://www.overberg.co.uk/default.asp
Ocean Flow Energy	C	H-Axis Turbine	UK	www.oceanflowenergy.com
OWWE (Ocean Wave and Wind Energy	W	Multiple	Norway	http://www.owwe.net/
Pacific Gas and Electric Company	C	FERC	USA	http://www.pge.com/
Pelagic Power AS	W	Wave Pump	Norway	http://www.pelagicpower.com
Pelamis Wave Power	W	Attenuator	UK	http://www.pelamiswave.com
Ponte di Archimede	C	Other	Italy	http://www.pontediarchimede.it/language_us/
Snohomish County PUD #1	C	FERC	USA	http://www.snopud.com
Pulse Generation	C	Oscillating Hydrofoil	UK	www.pulsegeneration.co.uk
Renewable Energy Holdings	W	Oscillating Wave Surge	AUS / UK	http://www.reh-plc.com/index.asp
Resolute Marine Energy, Inc.	W	Other	USA	http://www.resolute-marine-energy.com
Rhode Island Energy Group, LLC		FERC	USA	none
Robert Gordon University	C	Multiple	UK	www.rgu.ac.uk/cree
Scientific Aps&Rsch Assoc. (SARA)	W	Other	USA	http://www.sara.com/RAE/ocean_wave.html
Scotrenewables	C	H-Axis Turbine	UK	http://www.scotrenewables.com
SDE	W	PSHS	Israel	http://www.sde.co.il
Sea Power International AB	W	Attenuator	Sweden	http://www.seapower.se/english.htm
Seabased AB	W	Point Absorber	Sweden	http://www.seabased.com
Seawood Designs Inc	W	Point Absorber	Canada	http://www.surfpower.ca/
SEEWEC Consortium	W	Point Absorber	Belgium	http://www.seewec.org
SeWave Ltd	W	OWC	Faroe Islands	http://www.sewave.fo/
Shamil Ayntrazi	W	Wave Pump	USA	http://www.renewableenergypumps.com
SMD Hydrovision		Marine Engineering	UK	http://www.smd.co.uk
SRI International	W	Point Absorber	USA	http://www.sri.com/news/releases/120808.html
Statkraft	C	H-Axis Turbine	Norway	http://www.statkraft.com
Swanturbines Ltd.	C	H-Axis Turbine	UK	http://www.swanturbines.co.uk
Swell Fuel	W	Other	USA	http://swellfuel.com/
SyncWave Energy Inc.	W	Point Absorber	Canada	http://www.syncwavesystems.com
Teamwork Tech	C	H-Axis Turbine	Netherlands	www.teamwork.nl
The Engineering Business Ltd.	C	Oscillating Hydrofoil	UK	http://www.engb.com
Tidal Electric	C	Other	UK	http://www.tidalelectric.com
Tidal Energy Pty Ltd	C	V-Axis Turbine	Australia	http://tidalenergy.net.au/
Tidal Generation Ltd.	C	H-Axis Turbine	UK	http://www.tidalgeneration.co.uk
Tidal Hydraulic Generators Ltd.	C	H-Axis Turbine	UK	http://www.dev.onlinemarketinguk.net/THG/index.html
Tidal Sails	C	Other	Norway	http://www.tidalsails.com
Tidal Stream	C	H-Axis Turbine	UK	http://tidalstream.co.uk
Tocardo Tidal Energy Ltd.	C	H-Axis Turbine	Netherlands	http://www.tocardo.com
Town of Edgartown		FERC	USA	http://www.edgartown-ma.us
Trident Energy Ltd.	W	Point Absorber	UK	http://www.tridentenergy.co.uk
UEK Corporation	C	H-Axis Turbine	USA	http://www.uekus.com/
University of Edinburgh	W / C	Multiple	N.A.	http://www.see.ed.ac.uk/research/IES/
University of Southampton	W / C	Multiple	UK	http://www.southampton.ac.uk/ses/research/energy/maritime.html
University of Strathclyde	W / C	H-Axis Turbine	UK	http://www.strath.ac.uk/
Verdant Power	C	H-Axis Turbine	USA	http://www.verdantpower.com
Voith Siemens Hydro Power Generation	C	Other	Germany	http://www.voithsiemens.com/index_en.php
Vortex Hydro Energy	C	Other	USA	http://www.vortexhydroenergy.com
Vortex Oscillation Technology ltd	W	Other	Russia	http://www.vortexosc.com/
Water Wall Turbine	C	Other	USA	http://www.wwturbine.com/
Wave Dragon	W	Overtopping	Wales / Denmark	http://www.wavedragon.net/

Company	Wave [W] Current [C]	Type	Origin	URL
Wave Energy	W	Overtopping	Norway	http://www.waveenergy.no/
Wave Energy Centre	W	OWC	Portugal	http://www.wavec.org/
Wave Energy Technologies Inc.	W	Point Absorber	Canada	http://www.waveenergytechnologies.com
Wave Energy Technology - NZ	W	Attenuator	New Zealand	http://www.wavenergy.co.nz/home
Wave Power Plant Inc.	W	Point Absorber	USA	http://www.wavepowerplant.com
Wave Star Energy	W	Point Absorber	Denmark	http://www.wavestarenergy.com
Wave Star Energy ApS	W	Other	Denmark	http://www.wavestarenergy.com/
Waveberg Development	W	Attenuator	Canada	http://www.waveberg.com/
WaveBob Limited	W	Point Absorber	Ireland	http://www.wavebob.com
WAVEenergy AS	W	Other	Norway	http://www.wavessg.com/
Wavegen (Voith Siemens)	W	OWC	United Kingdom	http://www.wavegen.com/
WavePlane Production	W	Overtopping	Denmark	http://www.waveplane.com
Wind Waves And Sun	W	Other	USA	http://www.windwavesandsun.com/
Woodshed Technologies Ltd.	C	H-Axis Turbine	Australia	http://www.woodshedtechnologies.com.au

Appendix E – Report Exhibits

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8

Chapter 9

Chapter 10

Chapter 11

Chapter 12

Appendix F – Report References and Sources

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Appendix G – Contractors, Contributor, and Selected Consultations

Contractors

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Applied Ocean Physics and Engineering
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Tidewalker Associates

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Appendix H – Abbreviations and Acronyms

ABS
American Bureau of Shipping

AC
alternating current

ACI
American Concrete Institute

ACM
advanced composite material

ADCP
Acoustic Doppler current profilers

AIS
Automatic Identification System

AISC
American Institute of Steel Construction

ANSI
American National Standards Institute

API
American Petroleum Institute

ASCE
American Society of Civil Engineers

ASME
American Society of Mechanical Engineers

ASTM
American Society for Testing and Materials

AUV
autonomous underwater vehicle

AWS
American Welding Society

BLM
Bureau of Land Management

BWEA
British Wind Energy Association

CIGRE
International Council on Large Electric Systems

COLREG
Convention on the International Regulations Preventing Collisions at Sea

COP
construction and operation plan

CSA
Canadian Standards Association

CVA
certified verification agent

DC
direct current

DGPS
Differential global positioning system

DHS
Department of Homeland Security

DNV
Det Norske Veritas

DOE
Department of Energy

EMEC
European Marine Energy Centre

EMSA
European Maritime Safety Agency

EOM
electrical-optical-mechanical

EPA
Environmental Protection Agency

EPRI
Electric Power Research Institute

FERC
Federal Energy Regulatory Commission

FRP
fiber-reinforced polymers

GAP
general activity plan

GIS
geographic information system

GL
Germainischer Lloyd

GPS
global positioning system

HAT
highest astronomical tides (HAT)

HVDC
high voltage direct current

IACS
International Association of Classification Societies

ICE
International Electromechanical Committee

ICS
International Classification for Standards

IEA
International Energy Agency

IEC
International Electrotechnical Commission

IEEE
Institute of Electrical and Electronics Engineers (IEEE)

IMO
International Maritime Organization

ISO
International Organization for Standardization

LAT
lowest astronomical tides

LOTO
lock out/tag out

LRFD
Load and Resistance Factor Design

MARPOL
International Convention of Maritime Pollution Prevention

MMS
Minerals Management Service

NBS
National Bureau of Standards (NBS)

NDBC
National Data Buoy Center

NDT
nondestructive testing

NMD
Norsk Medisinadlepot (see NPD)

NOAA
National Oceanic and Atmospheric Administration

NPD
Norway Petroleum Directorate (See NMD)

NPDES
National Pollution Discharge Elimination System

NSPAC
National Standards Policy Advisory Committee

NTL
Notice to Lessee

OCS
Outer Continental Shelf

OGP
Association of Oil and Gas Producers

OREC
Ocean Renewable Energy Coalition

OREG
Ocean Renewable Energy Group

OPG
International Association of Oil and Gas Producers

OSHA
Occupational Safety and Health Administration

OWSC
oscillating wave surge converter

PEIS
Programmatic Environmental Impact Statement

PINC
potential incident non-compliance

ROV
remotely operated vehicle

SAP
site assessment plan

SCADA
supervisory control and data acquisition

SEMP
Safety and Environmental Management Program

SIM
Structural Integrity Management

SOLAS
Safety of Life at Sea

SPM
single-point mooring

SQEMS
Safety, Quality, Environmental Management Systems

STCW
Standards and Training, Certification, and Watchkeeping

TC
technical committee

UEK
Underwater Electric Kite

UGW
ultrasonic guided wave

UNCLOS
United Nations Convention on the law of the Sea

USACE
United States Army Corps of Engineers

USCG
United States Coast Guard

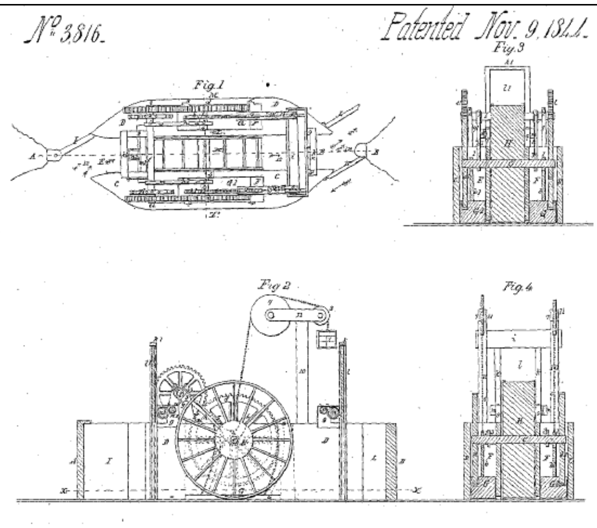
USGS
U.S. Geological Survey

VIV
vortex-induced vibrations

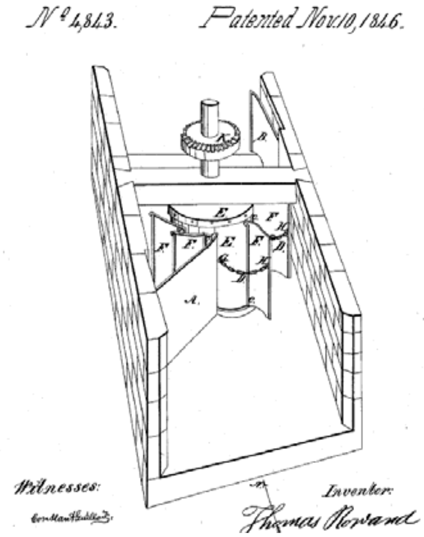
WaveEC
Wave Energy Centre

WHOI
Woods Hole Oceanographic Institution

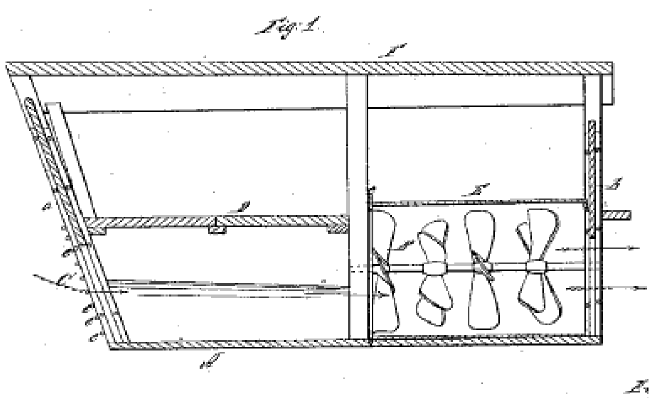
1844-1899



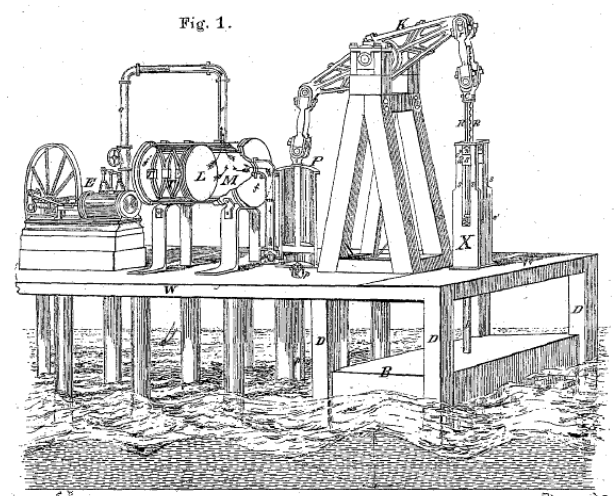
Tide Wheel
US Patent: 3816, Nov. 9, 1844
Inventor: John G. Ross, NY, USA



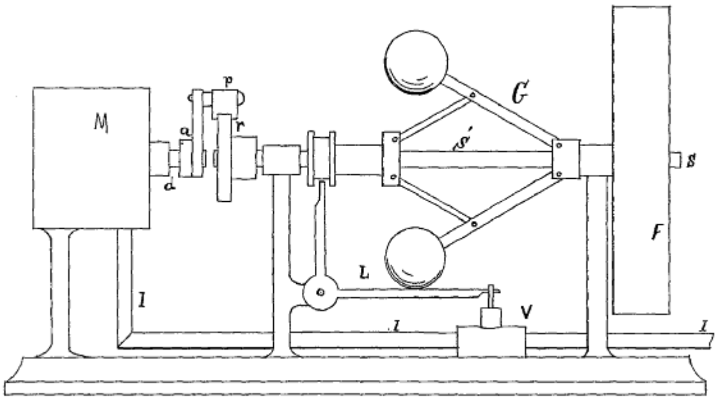
Tide Mill
US Patent: 4843, Nov. 1846
Inventor: Thomas Rowand, PA, USA



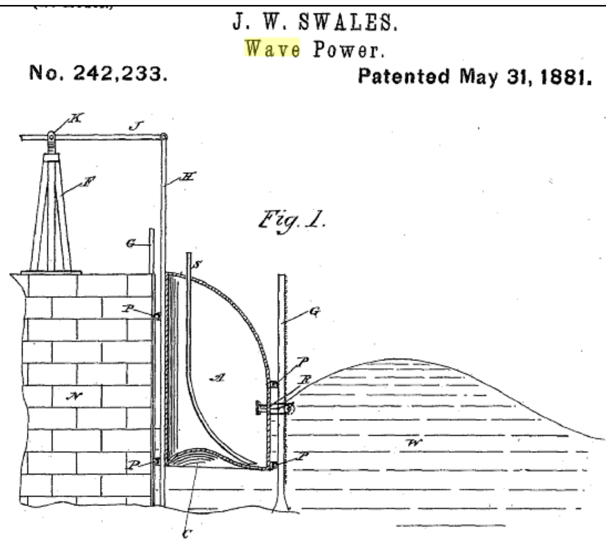
Improvement in Portable Water Power
US Patent 61362, January 1867
Inventor: Abram Rowe, IL, USA



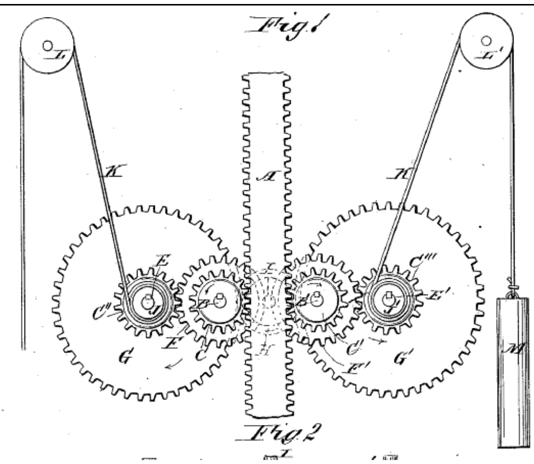
Improvement in Wave Powers
US Patent: 138,474, May, 1873
Inventor: Charles Buckner, CA, USA



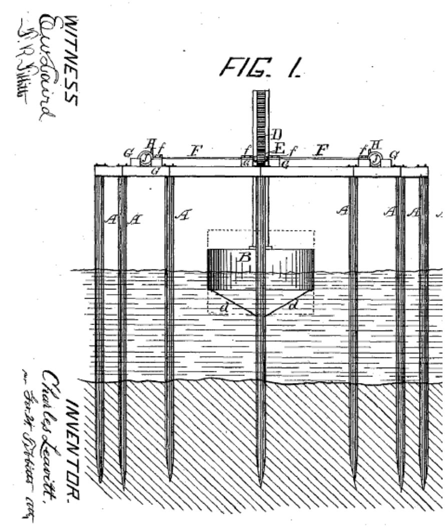
Wave Motor
US Patent: 241,800, May, 1881
Inventor: George B. Grant, MA, USA



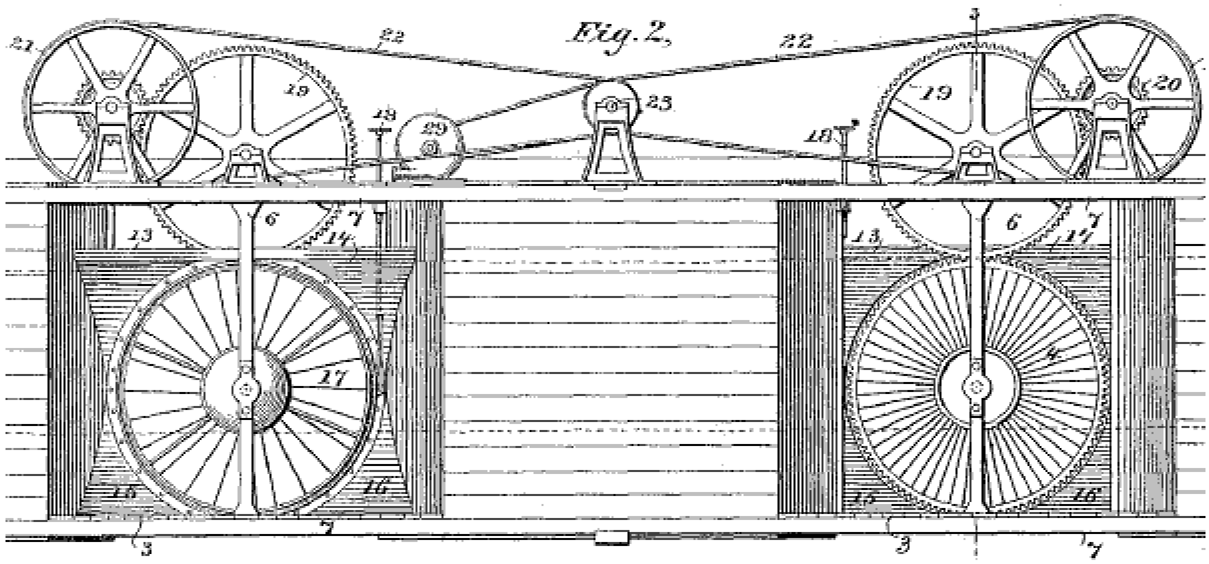
Wave Power
US Patent: 242,233, May 31, 1881
Inventor: John Swales, CA, USA



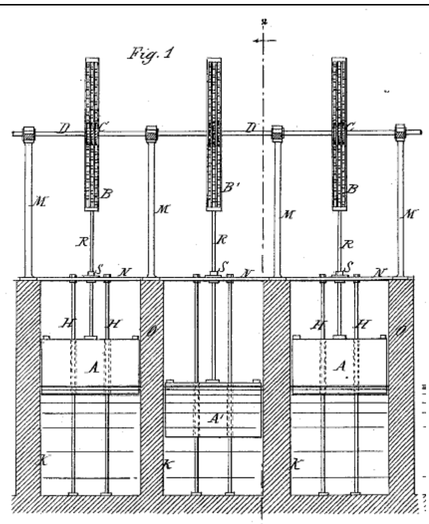
Tidal Power
US Patent: 332,875, May 1, 1885
Inventors: Brussard & Gates, KS, USA



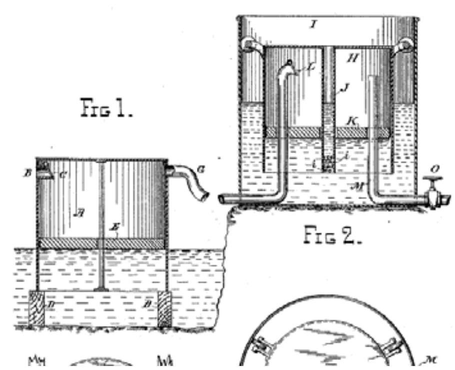
Mechanism for Utilizing Wave Power
US Patent: 321,229, June 1885
Inventor: Charles Leavitt, OH, USA



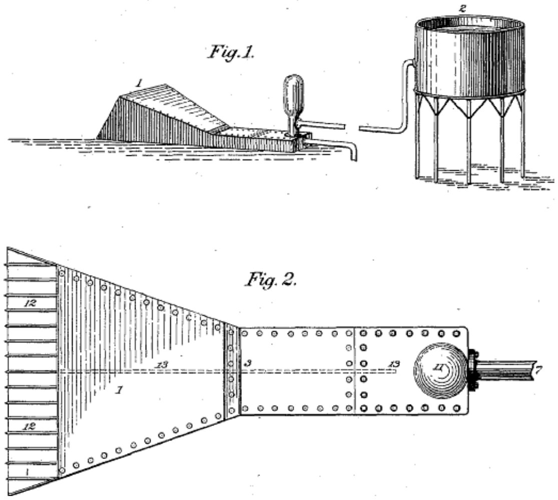
Floating Current Motor
US Patent 328593, October 1885
Assignee: River and Rail Electric Light Company, OH, USA



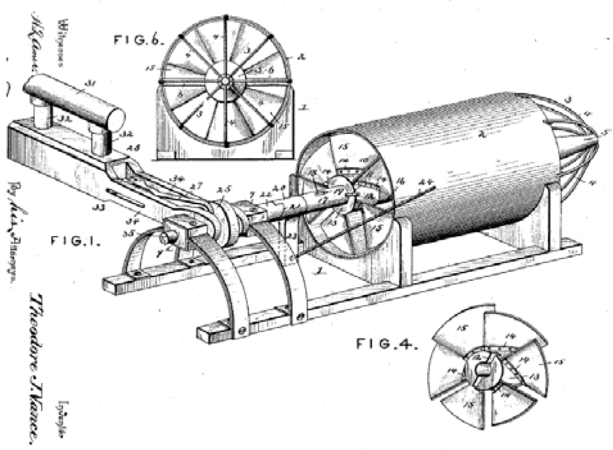
Hydraulic Marine Motor
US Patent: 366,768, June 1887
Inventor: Joseph Elias, SYRIA



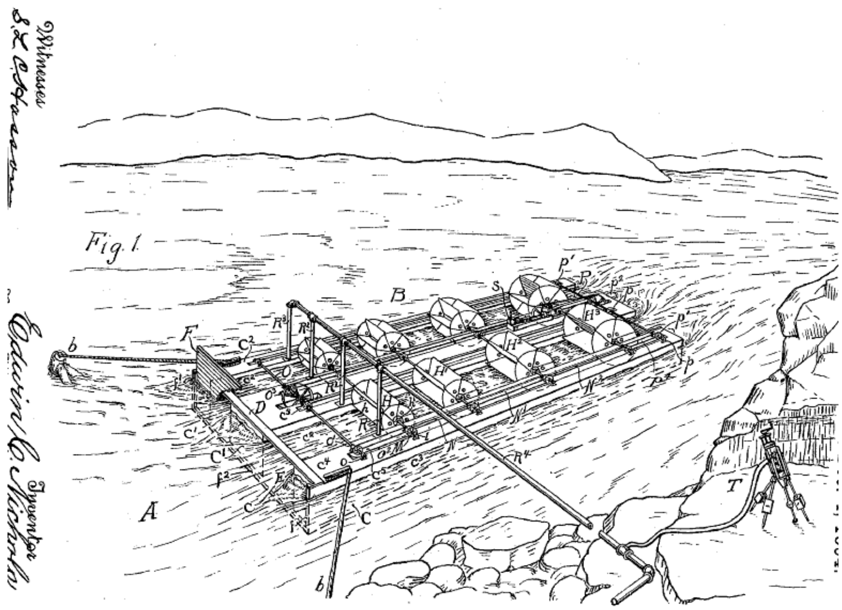
Surf-Power Machine
US Patent: 416,972, December 1889
Inventor: Henry Thomas, CA, USA



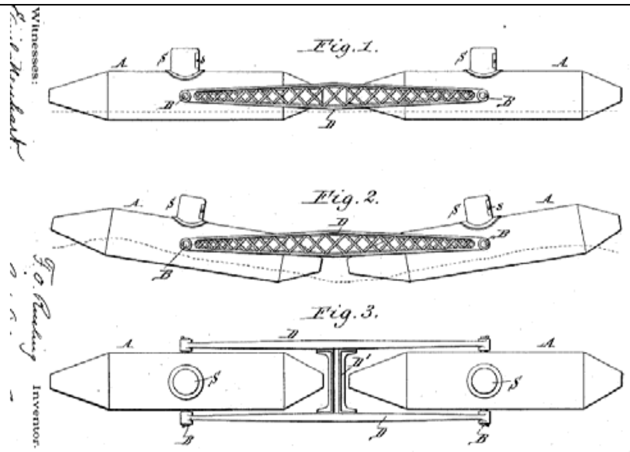
Apparatus for Utilizing the Force of Waves
US Patent: 430,790, June 24, 1890
Inventor: F. Starkenberg, MA, USA



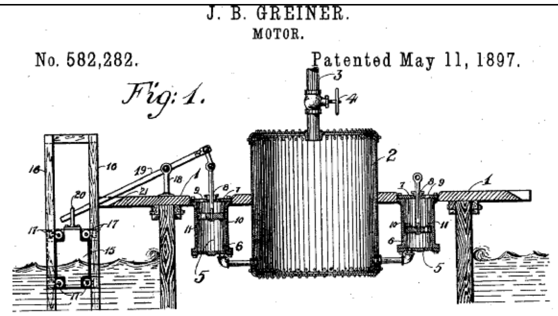
Water Motor
US Patent: 507294, October 1893
Inventor: Theodore Vance MO, USA



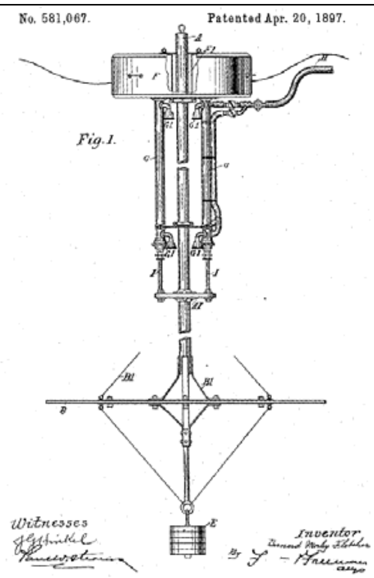
Apparatus for Generating Compressed Air
US Patent: 530,118, December 1894
Inventor: Edwin C. Nichols, MS, USA



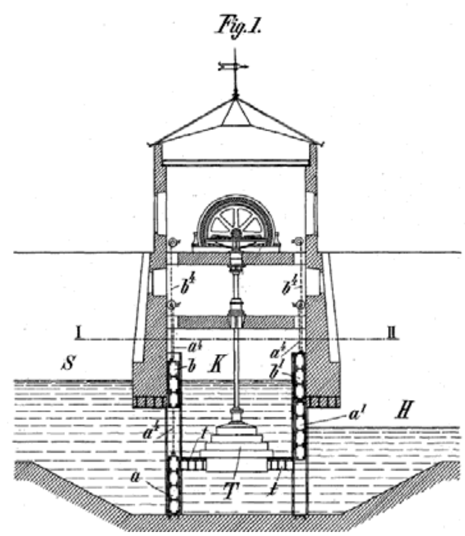
Wave Motor
US Patent: 541,631, June 25, 1895
Inventor: F. O. Rusling, NY, USA



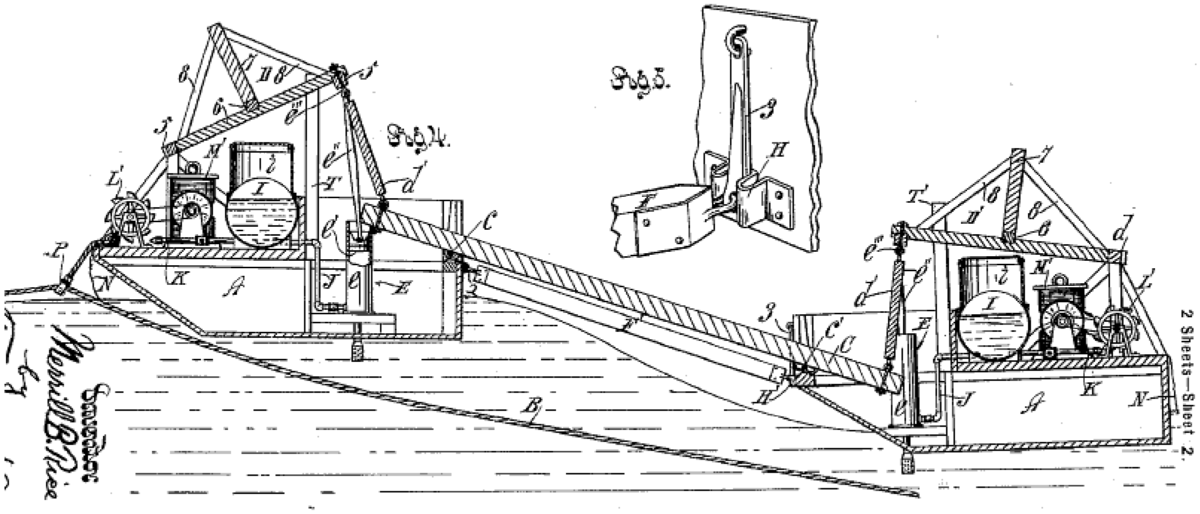
Motor (Wave)
US Patent: 582,282, Nov. 20, 1896
Inventor: John Greiner, FL, USA



Apparatus for Utilizing Power of Sea-Waves
US Patent: 581,067, June 20, 1896
Inventor: Bernard Fletcher, London, England

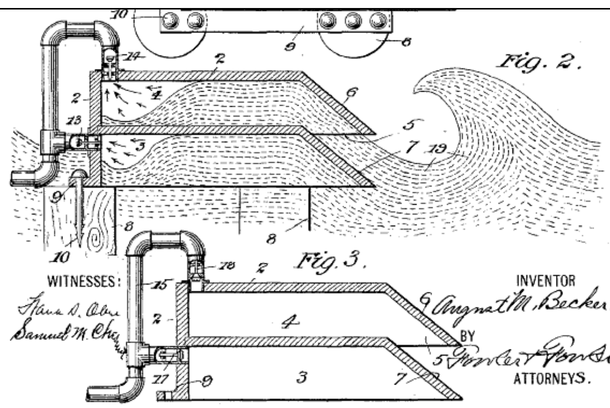


Tidal Motor
US Patent: 608,203 August, 1898
Inventor: Johan Knoblock, Hamburg, Germany

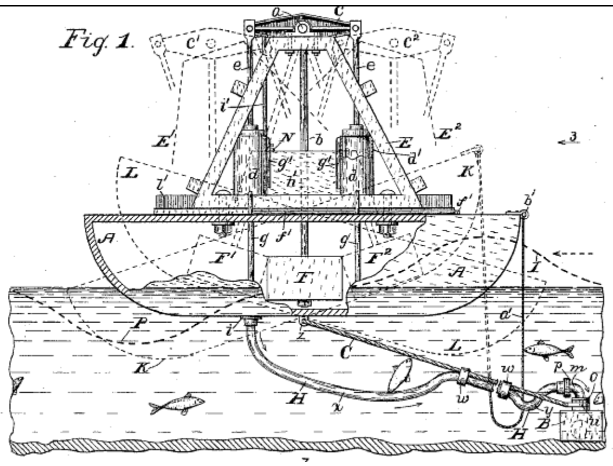


Wave Motor
US Patent: 632,826, September 1899
Inventor: Merrill B. Rice, CA, USA

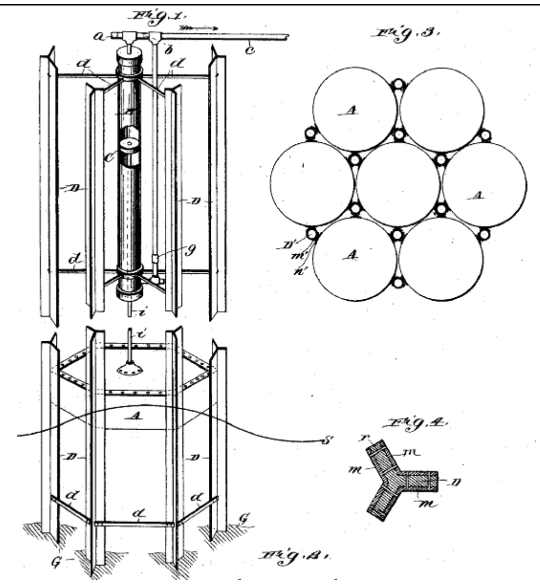
1900-1910



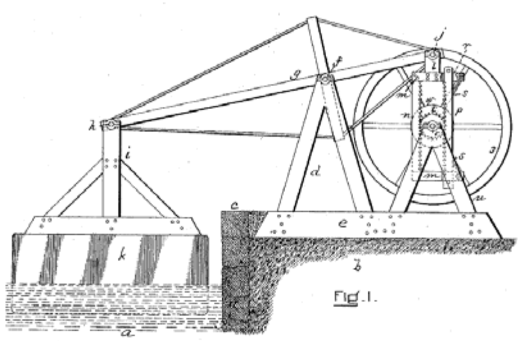
Marine Air Power Apparatus
US Patent: 655,541, August, 1900
Inventor: A. M. Becker, NY, USA



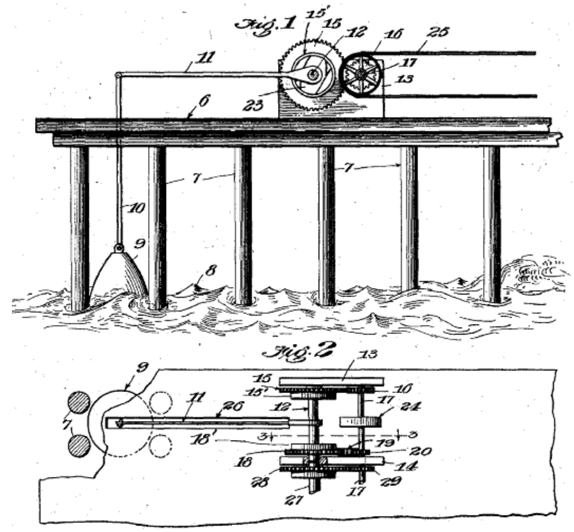
Wave Motor
US Patent: 656,645, August 1900
Inventor: George W. Hoff, NY, USA



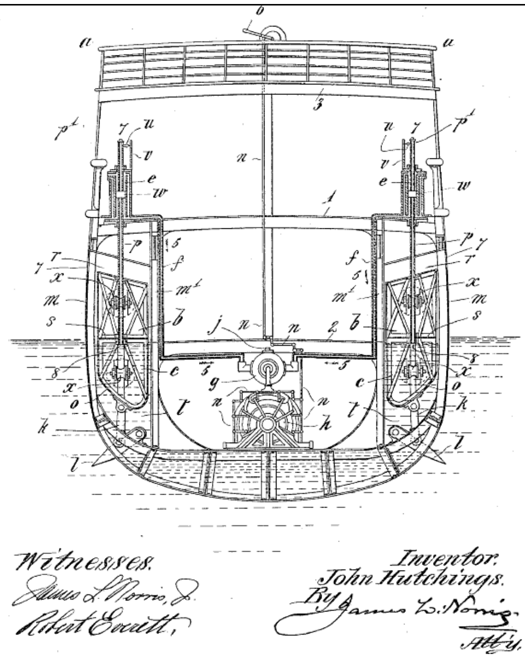
Wave-Motor
US Patent: 706620, August 1902
Inventor: Henry Williams, CA, USA



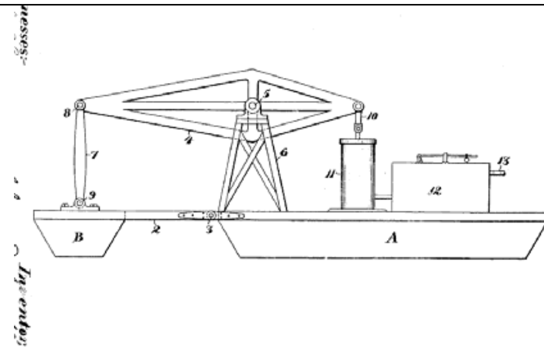
Tide-Motor
US Patent: 739,538, July 18, 1903
Inventor: Axel Fredson, MA, USA



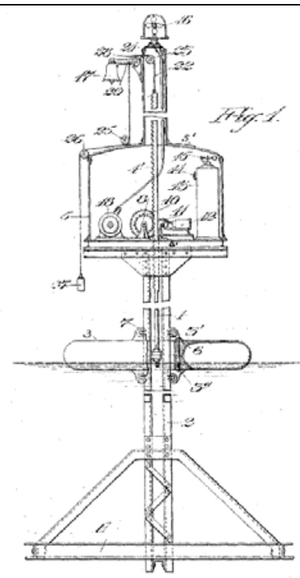
Wave Motor
US Patent: 791,366, May 1905
Inventor: Theodore Rapp, CA, USA



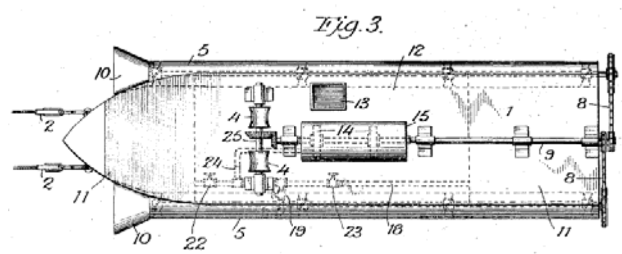
Wave Motor
U.S. Patent 787182, April 1905
John Hutchings, London, England



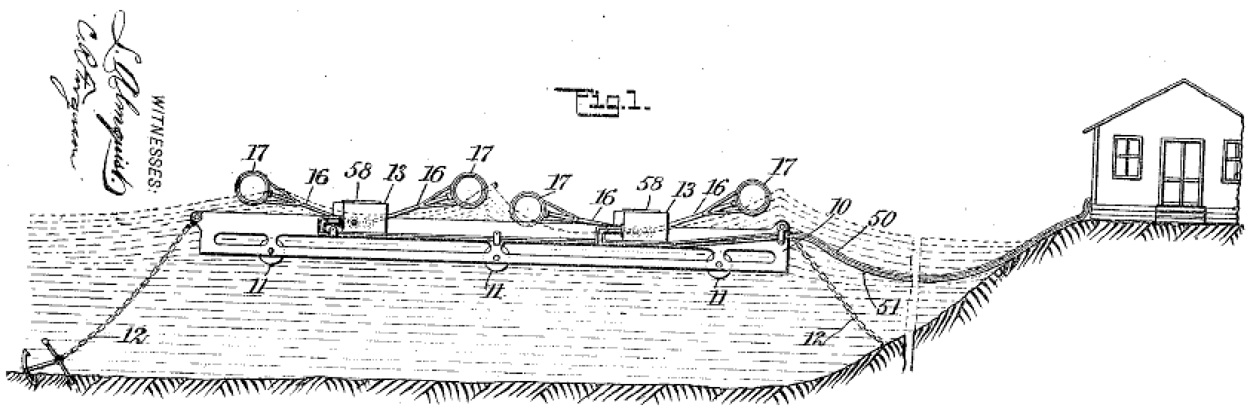
Wave Motor
US Patent: 816,934, Mar. 1906
Inventor: Charles Newell, CA, USA



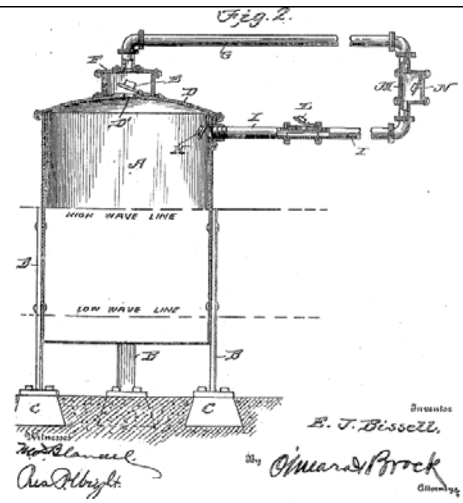
Wave Motor
US Patent: 852,232, April 1907
Inventor: Ernest Kohler, CA, USA



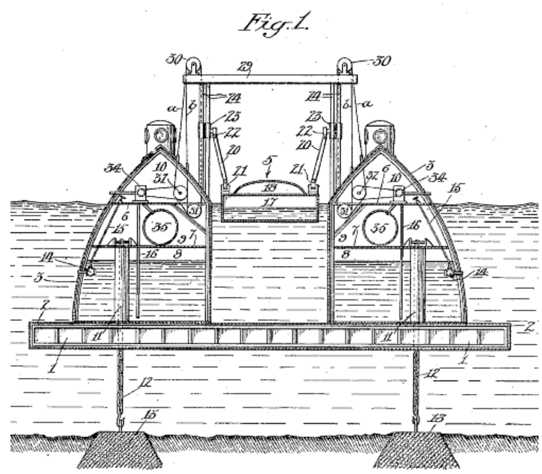
Current Motor
US Patent: 852022, April 1907
Inventor: John Kirschweng MT, USA



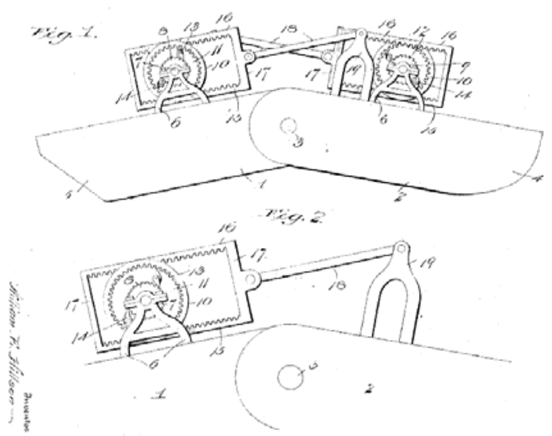
Wave Motor
US Patent: 855,258, May 28, 1907
Inventor: John W. Kealia, Territory of Hawaii



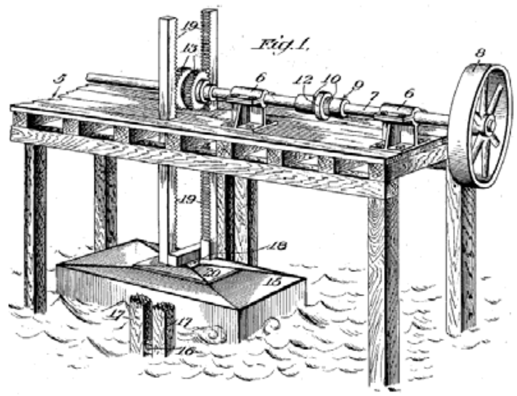
Wave Motor
US Patent: 875,042, Dec. 1907
Inventor: Edward Bissell, MI, USA



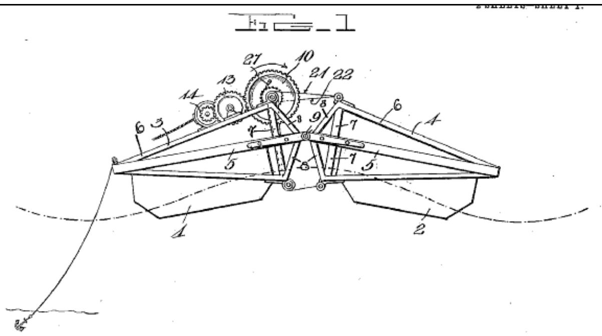
Wave Motor
US Patent: 879,992, February, 1908
Inventor: George Wilson, CA, USA



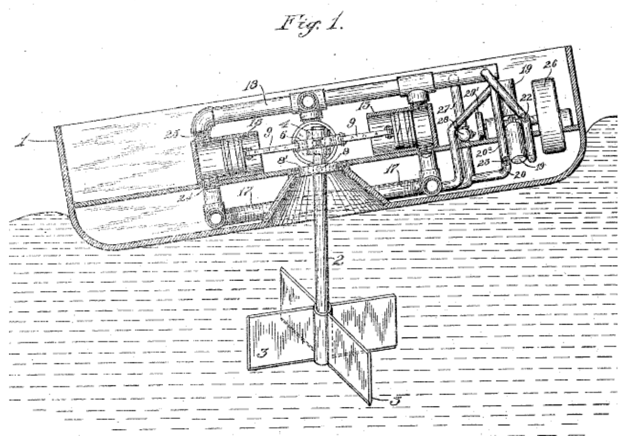
Wave Motor
US Patent 882,883, March 1908
Inventor: William Hillson, WI, USA



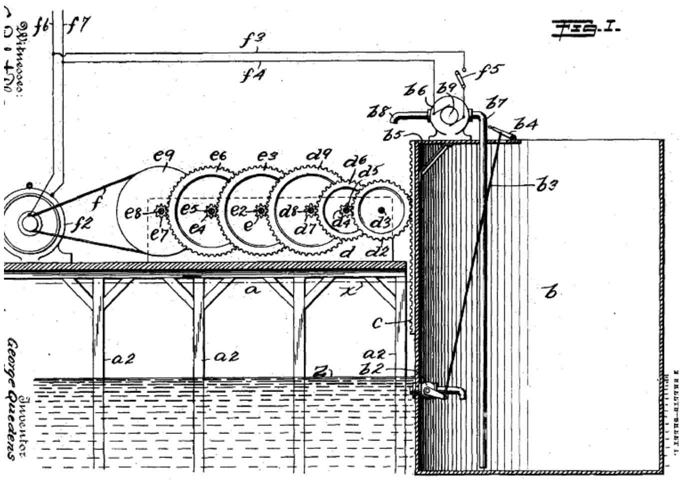
Wave Motor
US Patent: 884,080, April 1908
Inventor: George Fallis, CA, USA



Wave Motor
US Patent: 917,411, April 1909
Inventor: Casella & Reynolds, CA, USA

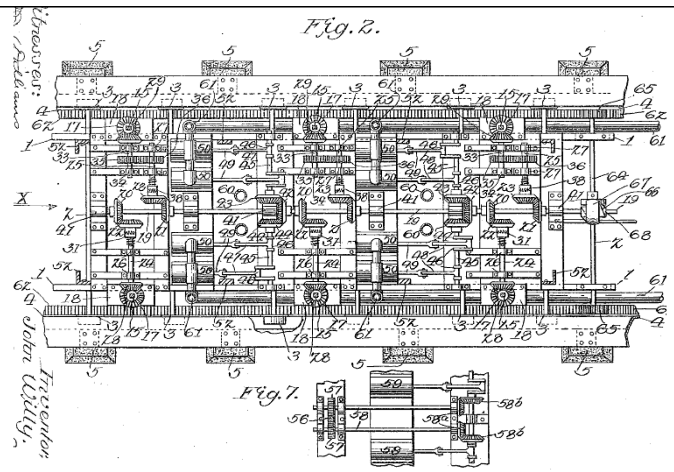


Wave-Motor
US Patent: 937,712, October 1909
Inventor: James D. McFarland, CA, USA

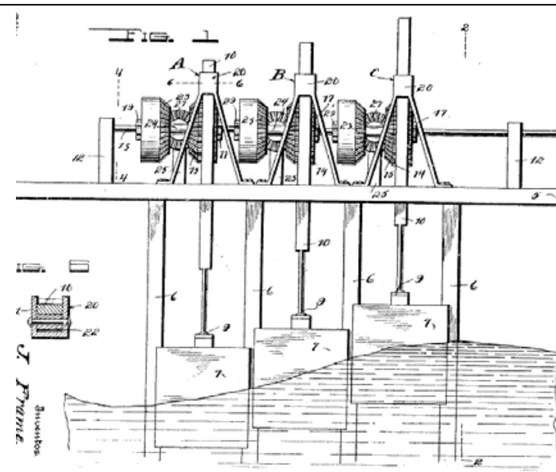


Tide Motor
US Patent: 975,157, Nov. 1910
Inventor: George Quedens, NY, USA

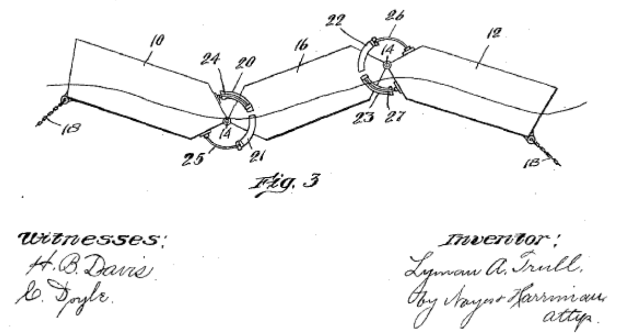
1911-1920



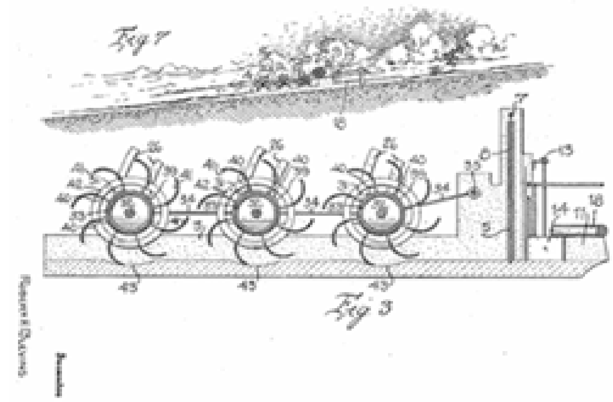
Mechanism for the obtainment of motive power from the waves of the ocean, lakes, or other large bodies of water
US Patent: 1,045,654, Nov. 1912
Inventor: John Willy, CA, USA



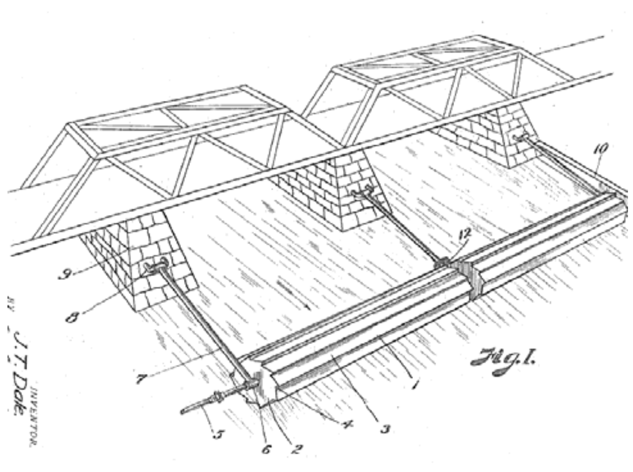
Wave Motor
US Patent: 1,061,061, May 1913
Inventor: John Frame, Searsport, ME



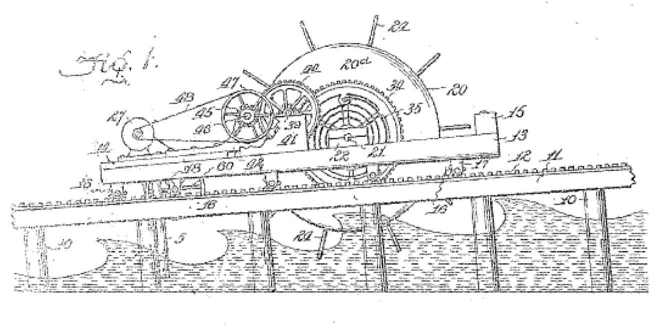
Wave Motion Motor
US Patent: 1,078,323, Nov. 11, 1913
Inventor: L. A. Trull, NH, USA



Hydraulic Power Unit ("from the bed of a flowing stream or river")
US Patent: 1,202,657, October, 1916
Inventor: Robert Blevins, TN, USA

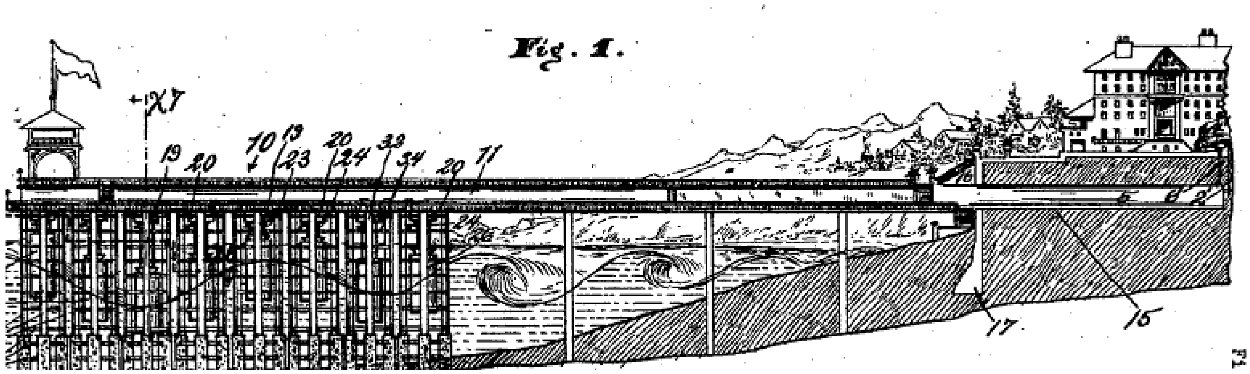


Current Motor
US Patent: 1,263,865, April 1918
Inventor: James Dale, KS, USA

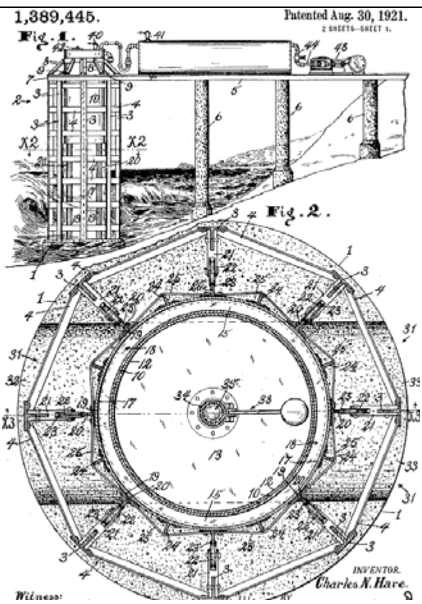


Wave Motor
US Patent 1,289,533, Dec. 31, 1918
Inventor: Benjamin H. Pelton, CA, USA

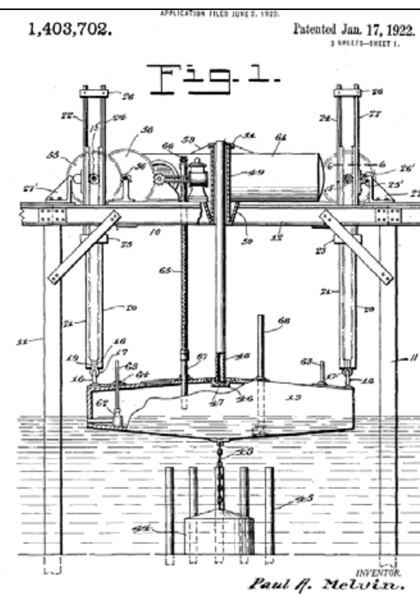
1921-1930



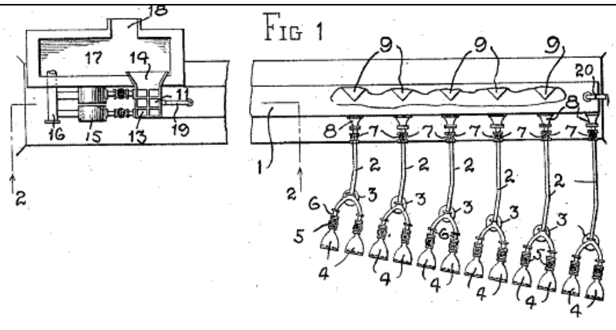
Ocean Compressed-Air Power
US Patent: 1,623,341, August, 17, 1921
Charles N. Hare, OH, USA



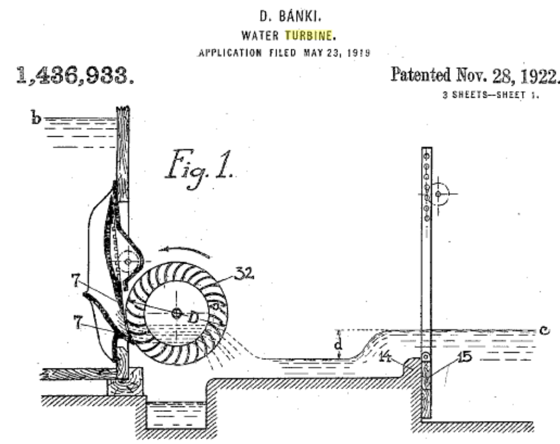
Ocean Compressed Air Power
US Patent: 1,389,445, Aug. 30, 1921
Inventor: Charles Hare, OH, USA



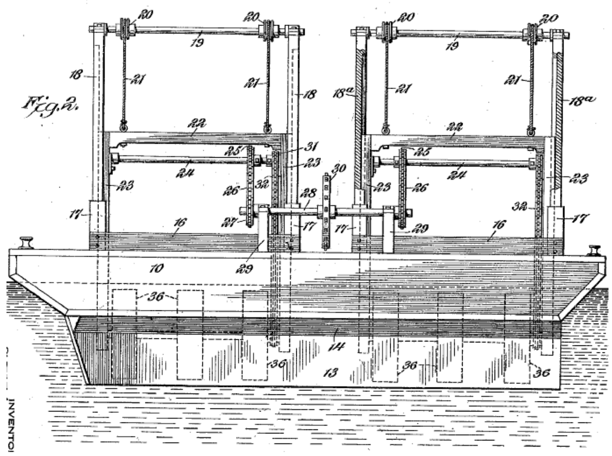
Water Motor
US Patent: 1,203,702, January 1922
Inventor: Paul Melvin, IL, USA



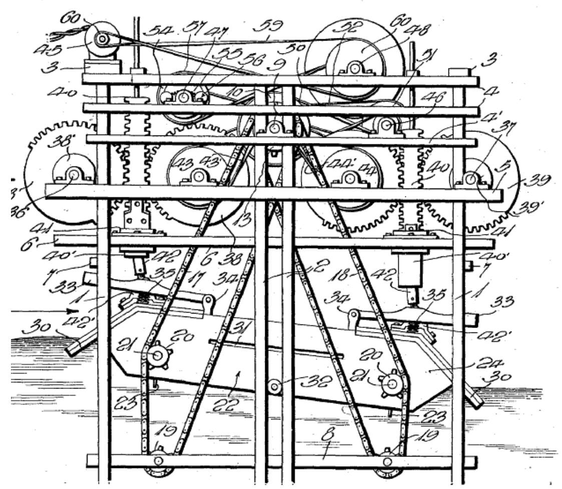
Method of and Apparatus for Obtaining Power from the Surf
US Patent: 1,418,680, June 1922
Inventor: William Scott, NJ, USA



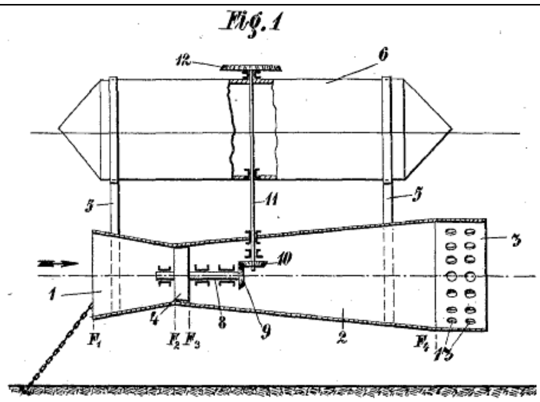
Water Turbine
(Free Stream Turbine)
US Patent: 1,436,933, Nov. 28, 1922
Inventor: Donat Banki, Budapest, Hungary



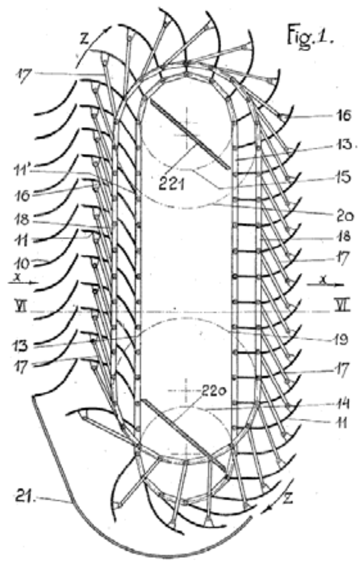
Current Motor
US Patent: 1,441,361 Jan. 9, 1923
Inventor: Samuel Lindsey, AR, USA



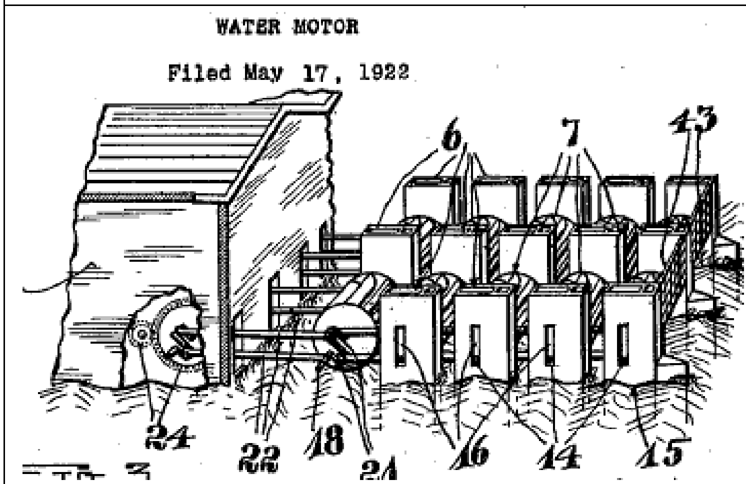
Wave Motor
US Patent: 1,471,222, October 1923
Inventor: William M. Taylor, VA, USA



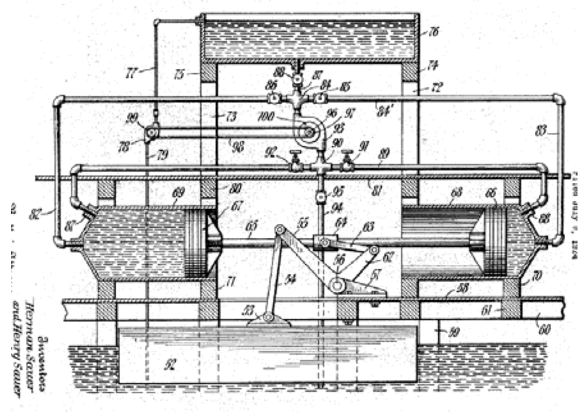
Water Turbine
US Patent: 1,476,229, Dec. 4, 1923
Inventor: Eduard Suess, Vienna, Austria



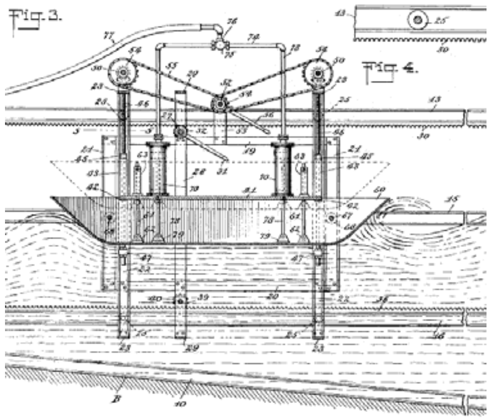
Chain turbine to exploit velocity of flowing fluids
US Patent: 1,481,397, January 1924
Inventor: Armin Teteleni, Hungary



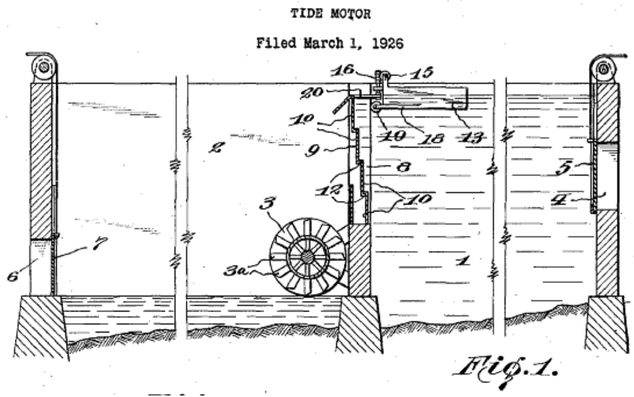
Water Motor
US Patent: 1,498,707, June 1924
Inventor: Frederick Wilcott, CA, USA



Tide Motor
US Patent: 1,555,487, Sept. 1925
Inventors: Herman and Henry Sauer
NY, USA

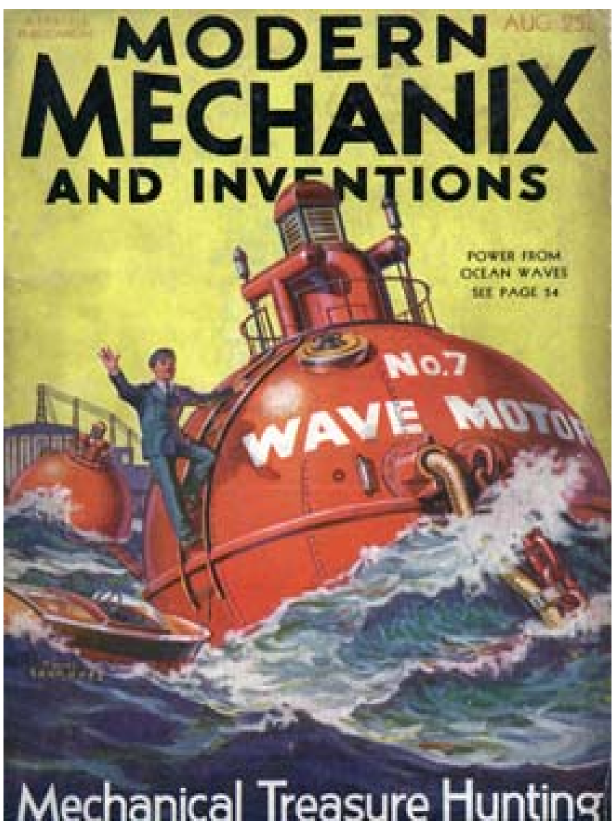


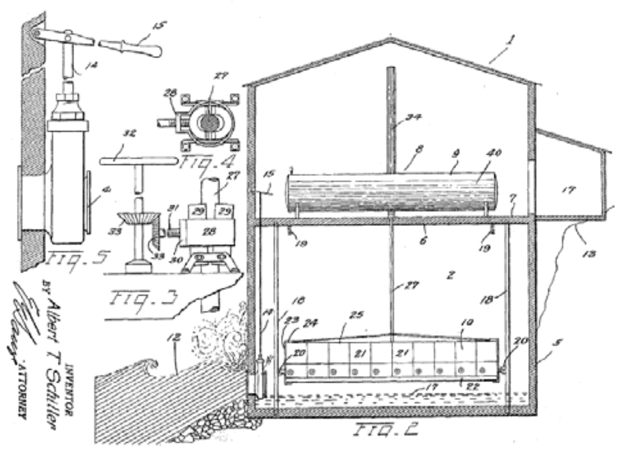
Wave Motor
US Patent: 1,647,025, June 7, 1927
Inventor: Ferdinand Stich, NY, USA



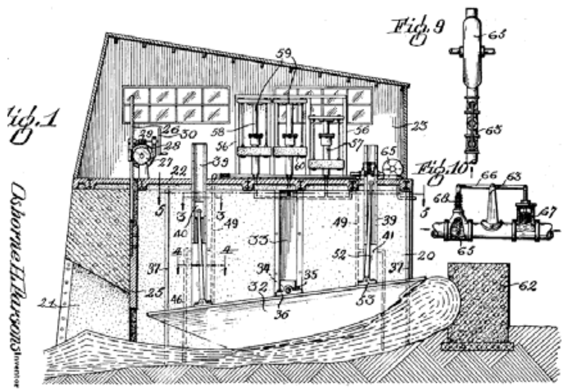
Tide Motor
US Patent: 1,670,140, May 15, 1928
Inventor: Edward Cole, NY, USA

1931-1970

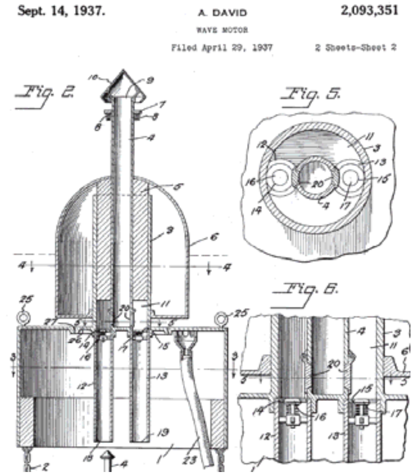




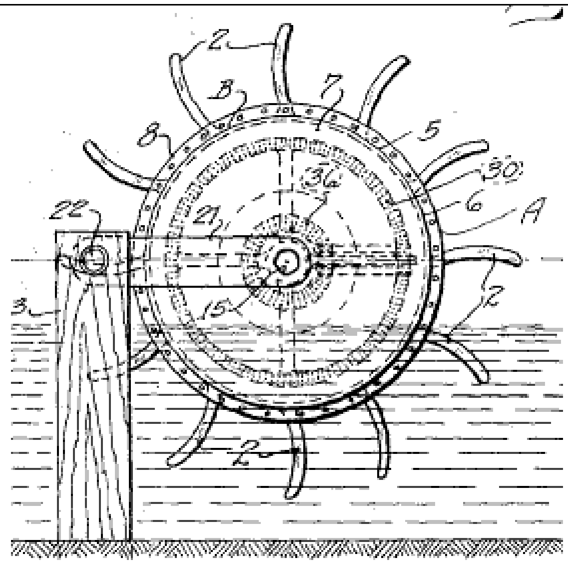
Tidal Motor
US Patent: 1,885,866, November 1932
Inventor: Albert Schiller, WA, USA



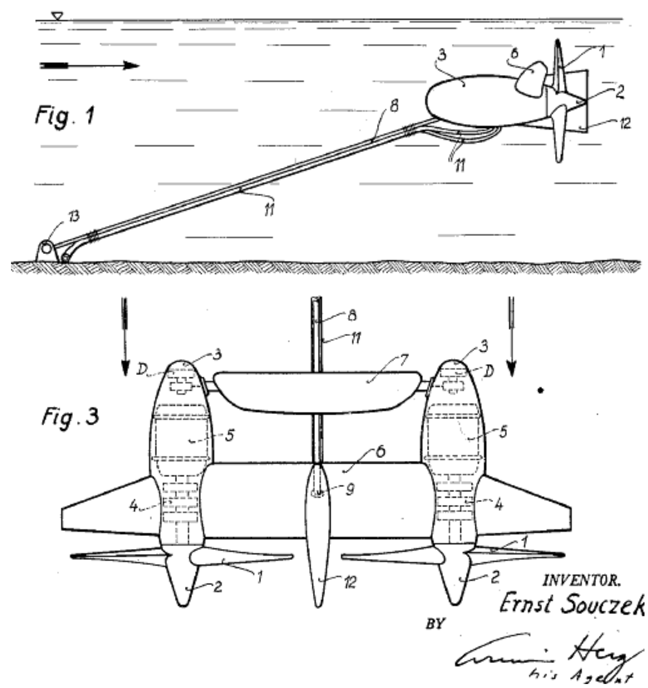
Wave Motor
US Patent: 1,930,958, October 17, 1933
Inventor: Osborne Parsons, Nova Scotia, Canada



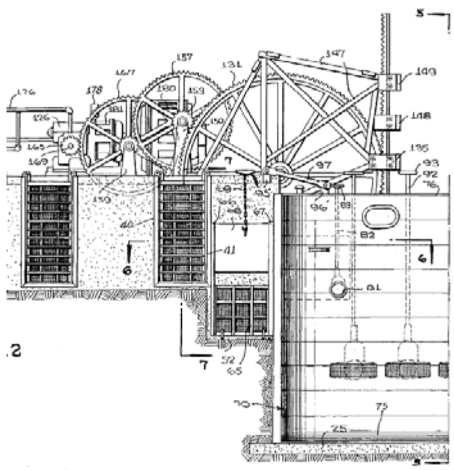
Wave Motor
US Patent: 2,093,351, Sept. 14, 1937
Inventor, Andrew David, Wash. DC, USA



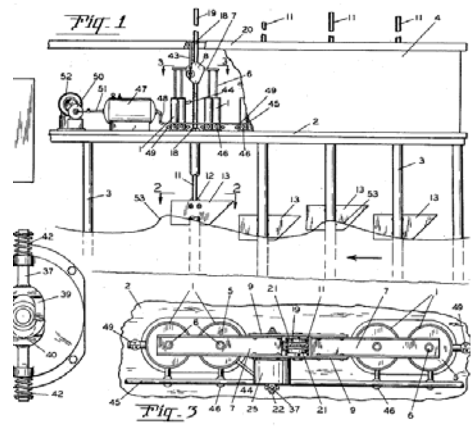
Power Generating Apparatus
US Patent: 2,097,286, Oct. 1937
Inventor: Lloyd S. McGee, MO, USA



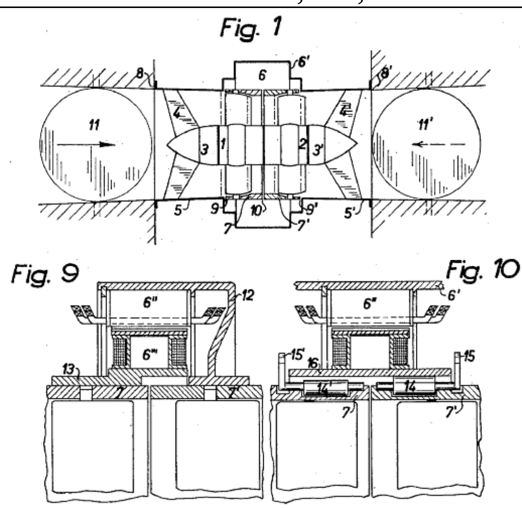
Stream Turbine
US Patent: 2,501,696, August 8, 1946
Inventor: Ernst Souczek, Vienna, Austria



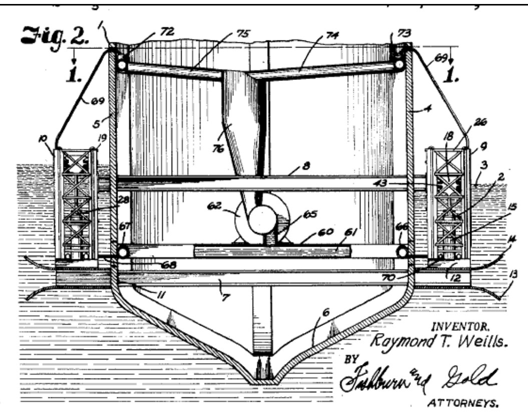
Tide Operated Power Plant
US Patent: 2,668,918, Feb 1954
Inventor: V.W. Howell, CA, USA



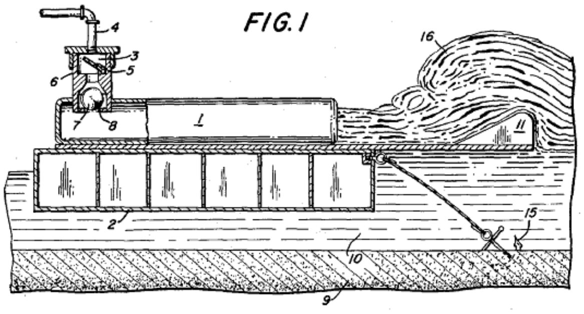
Ocean Wave Air Compressor
US Patent: 2,706,077, April 12, 1955
Inventor: Seral Searcy, OR, USA



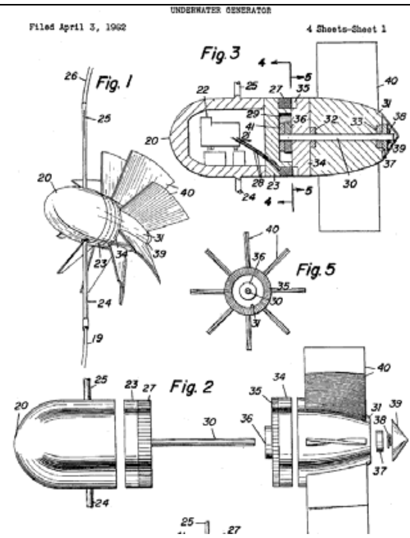
Turbine for Driving a Generator
US Patent: 2,782,321, Feb. 19, 1957
Inventor: Arno Fischer, Saarbruken, Germany



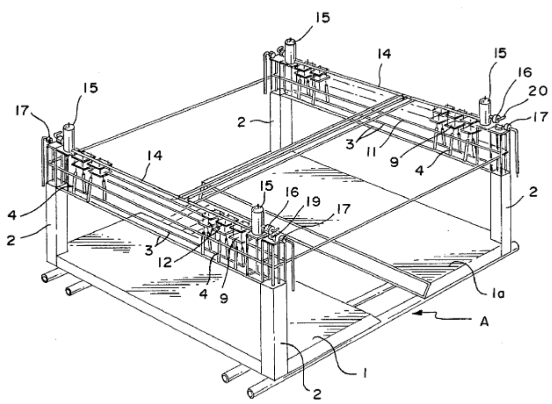
Buoy Motor
US Patent: 2,871,790, Feb. 3, 1959
Inventor: Raymond Weills, TX, USA



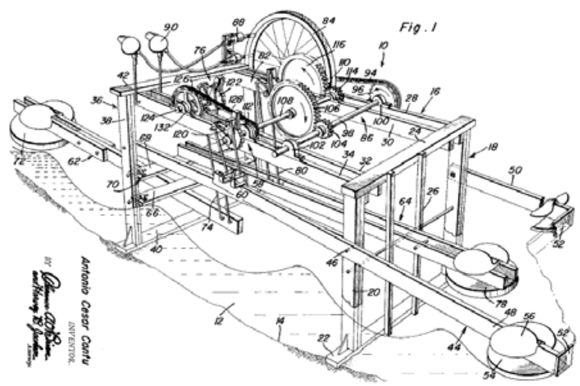
Air Compressors Utilizing the Kinetic and Potential Energy of Water Waves Common to Bodies of Water
US Patent: 3,149,776, Sept. 22, 1964
Inventor: William Parrish, CA, USA



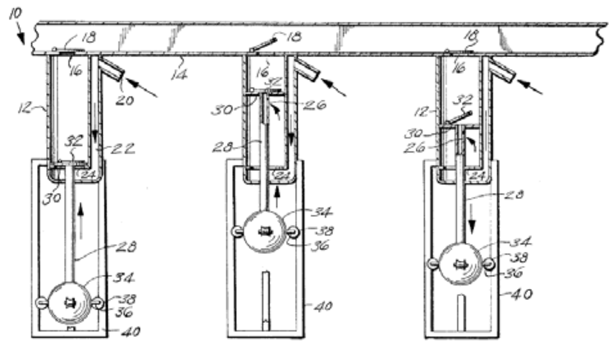
Underwater Generator
US Patent: 3,209,156, Sept. 28, 1965
Inventor: Arthur Stuble, CA, USA



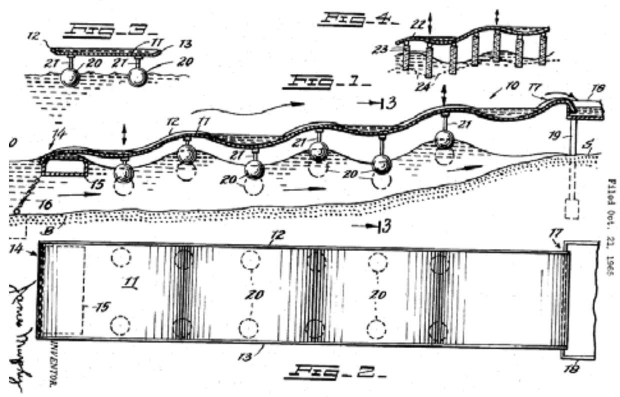
Wave Power Generator
US Patent: 5,499,889, March 19, 1966
Inventor: Myung-Shik Yim, Korea



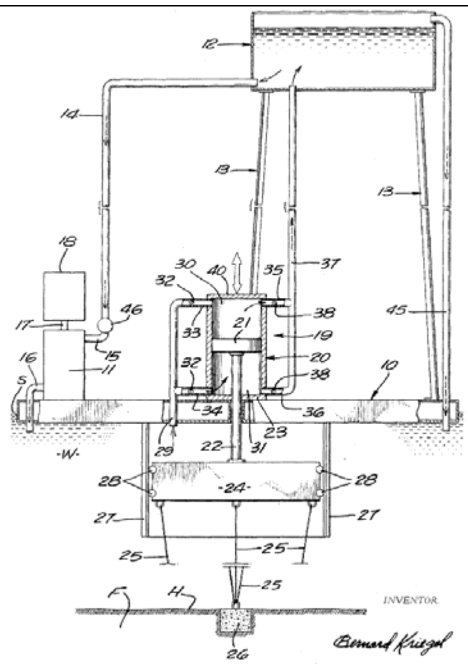
Ocean Wave Energy Generator
US Patent: 3,259,361, July 5, 1966
Antonio Cantu, Mexico



Ocean Powered Compressor
US Patent: 3,268,154, August 23, 1966
Inventor: Gyula Aranyi, PA, USA

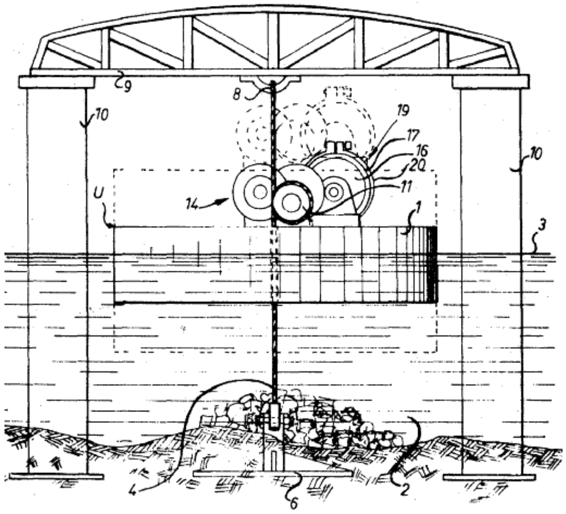


Wave Machine and Means for Raising Water
US Patent: 3,335,667, Aug. 15, 1967
Inventor: James Murphy, NY, USA

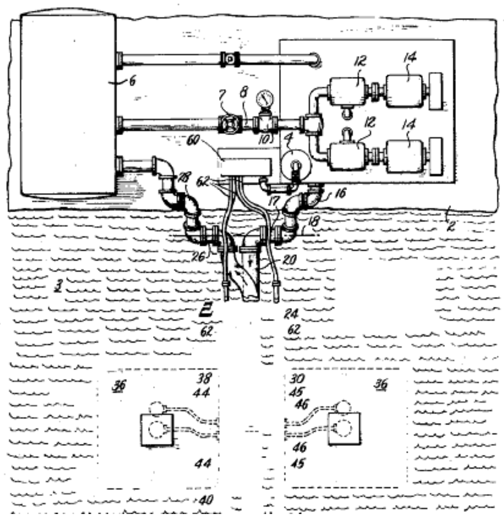


Power Generating System
US Patent: 3,487,228, Dec. 30, 1969
Bernard Kriegel, CA, USA

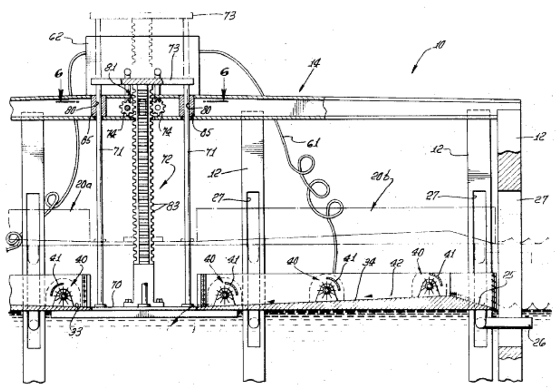
1971-1980



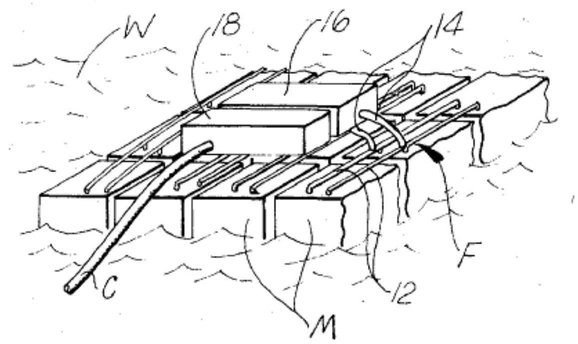
Tide Operated Power Plant
US Patent: 3,567,953, March 2, 1971
Inventor: Bruno Lord, Quebec, Canada



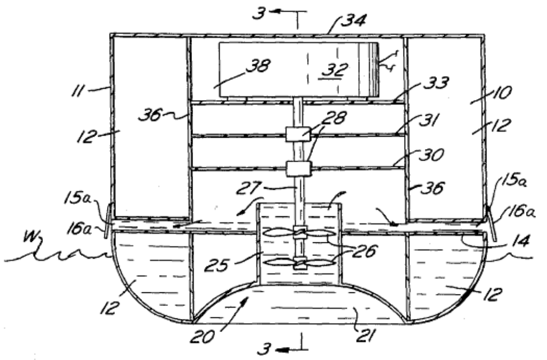
Wave Operated Power Apparatus
US Patent: 3,603,804, September 7, 1971
Inventor: Jesse Casey, AL, USA



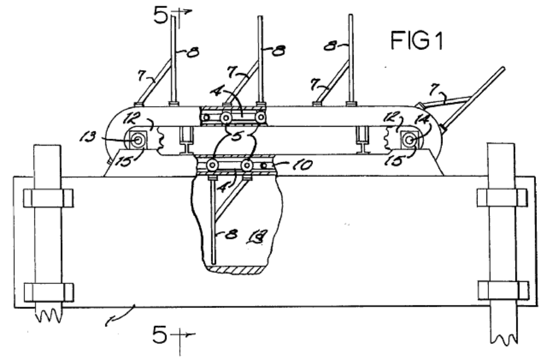
Electrical Power Plant Driven by
Ocean Waves and Tides
US Patent: 3,746,875, July 1973
Inventor: Joseph Donatelli, CA, USA



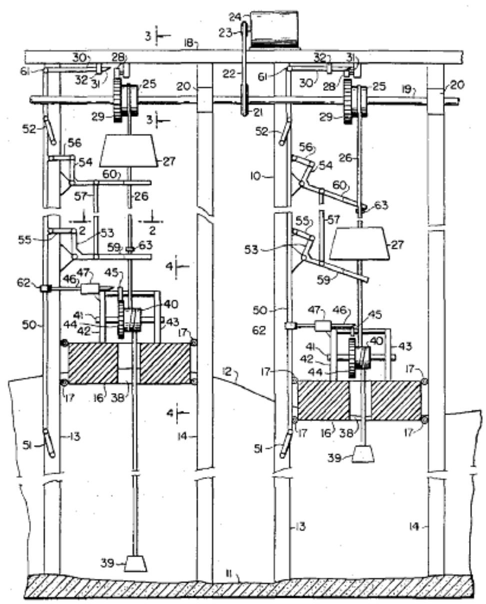
Conversion System for Providing Useful Energy from
Water Surface Motion
US Patent: 3,758,788, Sept. 1973
Inventor: Dale Richeson, HI, USA



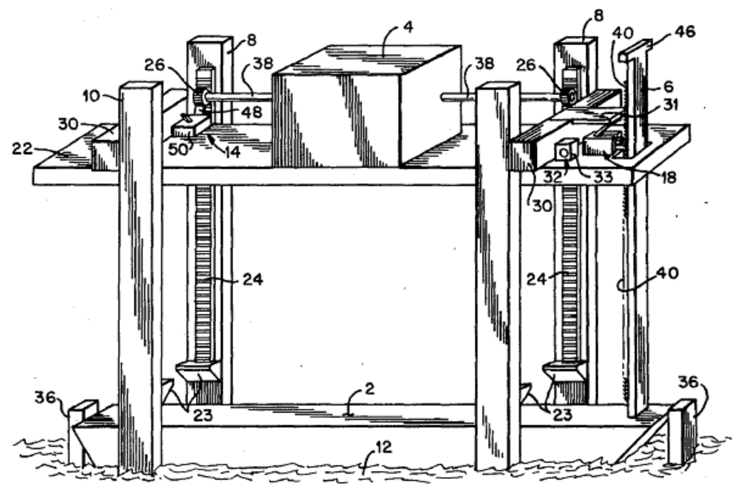
Wave Operated Power Plant
US Patent: 3,870,893, Mar. 11, 1975
Inventor: Henry Mattera, PA, USA



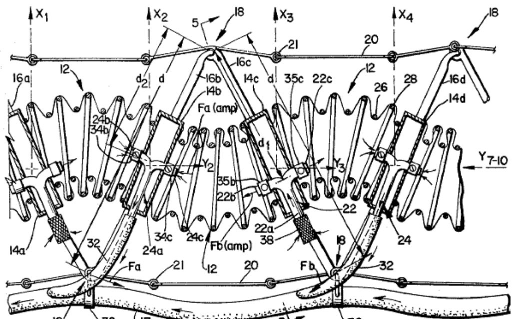
Tide Energy Conversion Device
US Patent: 3,882,320, May, 1975
Inventor: Edmund Schmeller, WA, USA



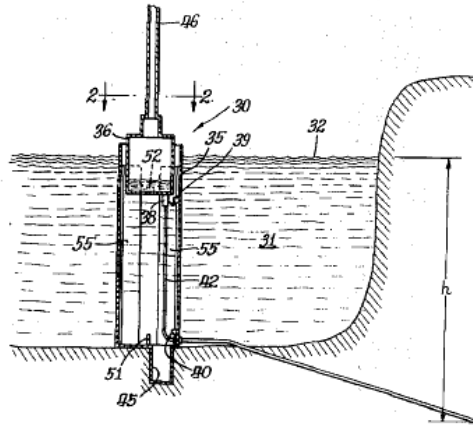
Wave Action Power Source
US Patent: 3,894,241, July 8, 1975
Inventor: Saul Kaplan, PA, USA



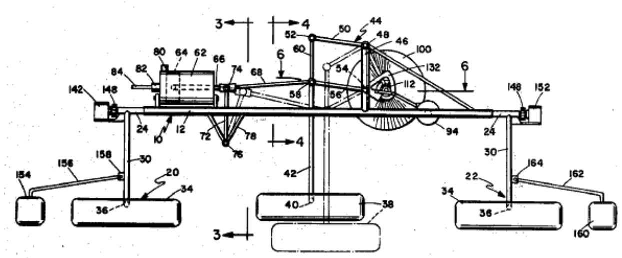
Tide Powered Electrical Generator
US Patent: 3,959,663, May 25, 1976
Inventor: Joseph V. Rusby, FL, USA



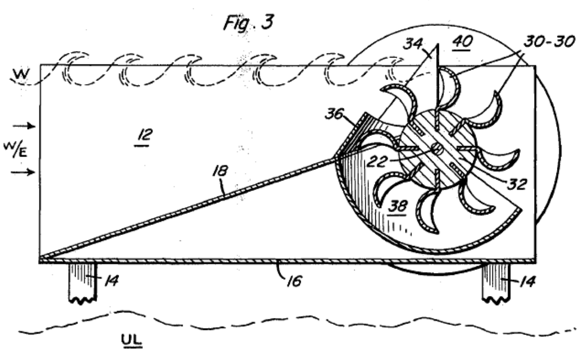
Water Action Powered Pump
US Patent: 3,961,863, June 8, 1976
Inventor: Lee Hooper III, FL, USA



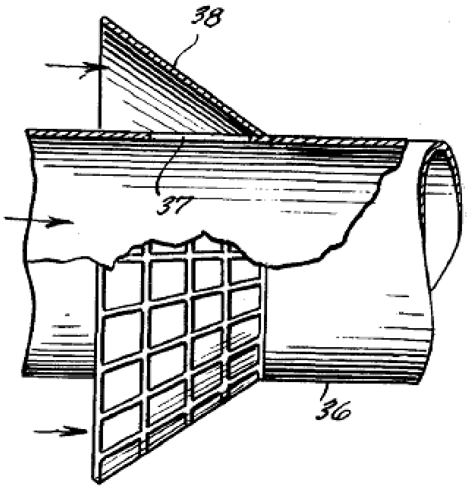
Energy Converting Hydraulic Buoyant Motor
US Patent: 3,961,479, June 8, 1976
Inventor: Ray C. Anderson, OK, USA



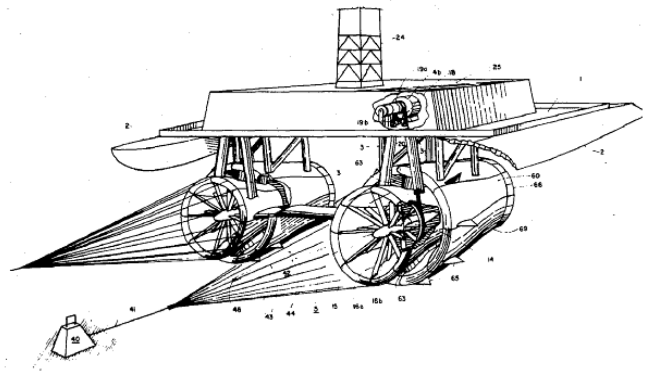
Power Generating Machine Actuated
by Ocean Swells
US Patent: 3,965,365, June 22, 1976
Inventor: Edward Parr, CA, USA



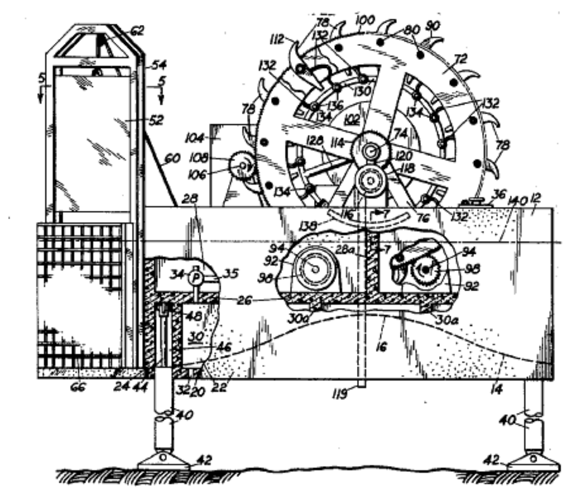
Wave Energy Machine
US Patent: 3,965,679, June 29, 1976
Inventor: Erasmus Paradiso, NY, USA



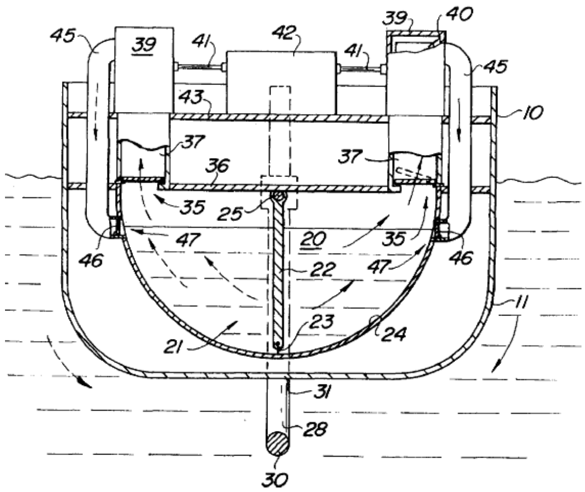
Flow Tubes for Producing Electric Energy
US Patent: 3,980,894, Sept. 14, 1976
Inventor: Philip Vary, NY, USA



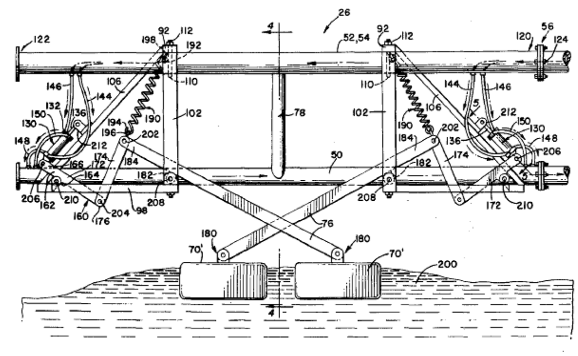
River Turbine
US Patent: 3,986,787, October 19, 1976
Inventor: William Mouton, LA, USA



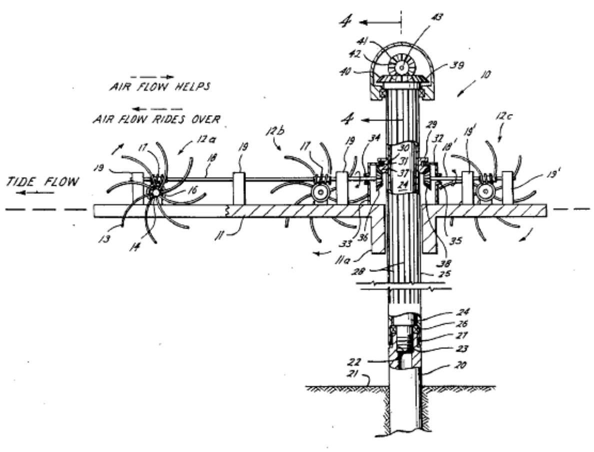
Wave and Current Operated Power
Generating Device
US Patent: 4,001,596, Jan. 4, 1977
Inventor: Earl Kurtzbein, WA, USA



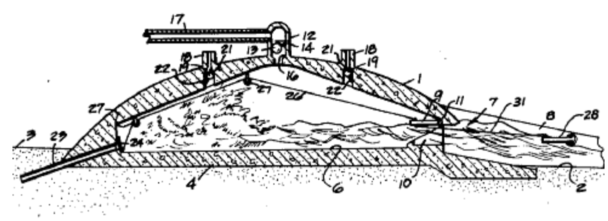
Wave Operated Power Plant
US Patent: 4,00,396, Feb. 22, 1977
Inventors: Mattera & Pitts, PA, USA



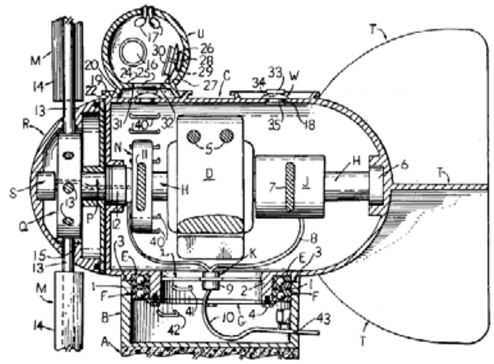
Wave Power Apparatus Supported by
Floats in Water
US Patent: 4,013,382, Mar. 22, 1977
Inventor: Richard Diggs, MO, USA



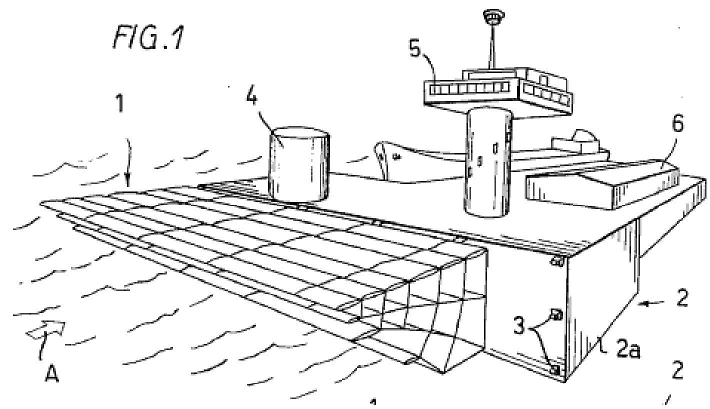
Apparatus for Generating Electricity and Power from
Natural Water Flow
US Patent: 4,023,041, May, 10, 1977
Inventor: Walter L. Chappell, TX, USA



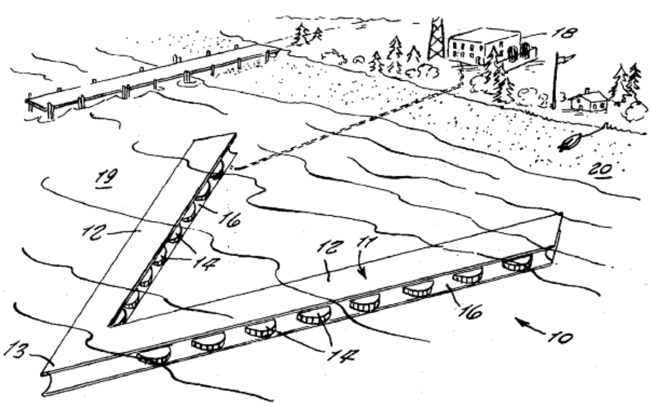
Shoreline Air Compressors wherein swell water pumps
the air
US Patent 4,022,549, May 10, 1977
Inventor: Harold Gregg, CA, USA



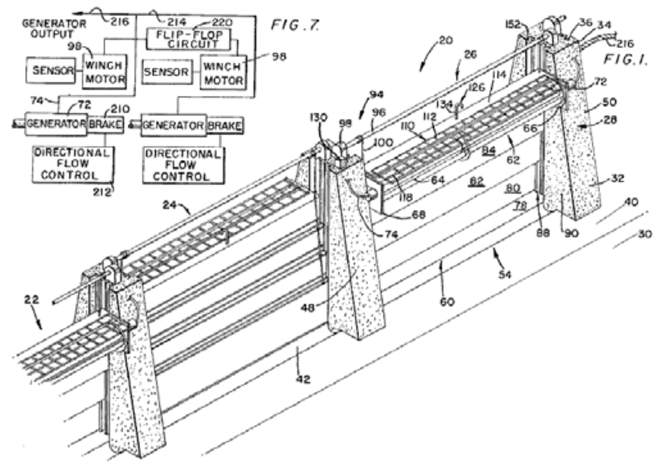
Underwater Turbine Operated by
Ocean Currents
US Patent 4,026,587, May 31, 1977
Robert & Dennis Hultman CA, USA



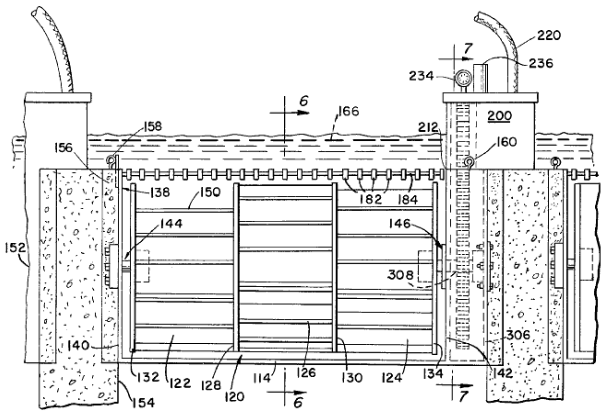
Wave Motor Comprised of a Submerged Floating
Network of Chambers Formed by Walls Permitting
Variable Geometry
US Patent: 4,036,563, July 1977
Inventor: Rolf Tornkvist, Finland



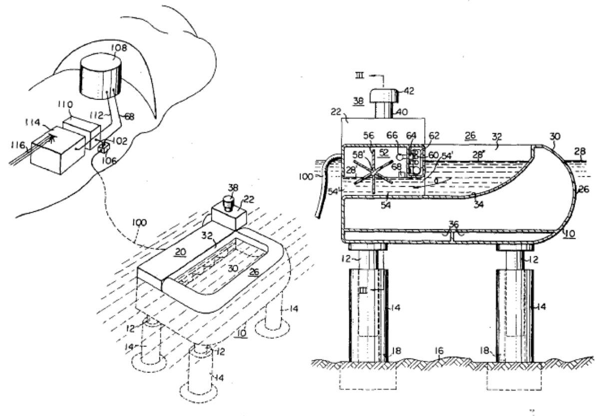
Ocean Tide and Wave Energy Converter
US Patent: 4,034,231, July 5, 1977
Inventor: John L. Conn, G. Spector, NY, USA



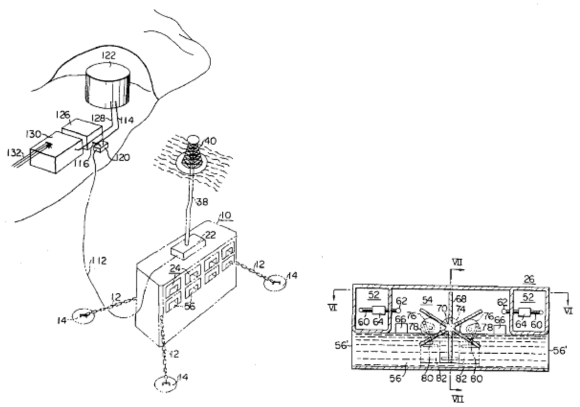
Tidewater Power Plant
US Patent: 4,039,847, Aug. 2, 1977
Inventor: Richard Diggs, MO, USA



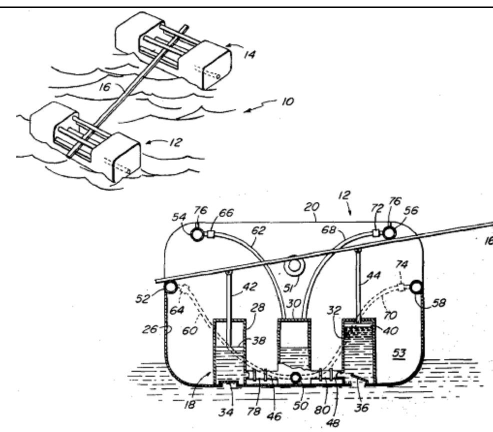
Modular Hydroelectric Power Plant
(converting water flowing in a stream)
US Patent: 4,053,787, Oct. 1977
Inventor: Richard Diggs, MO, USA



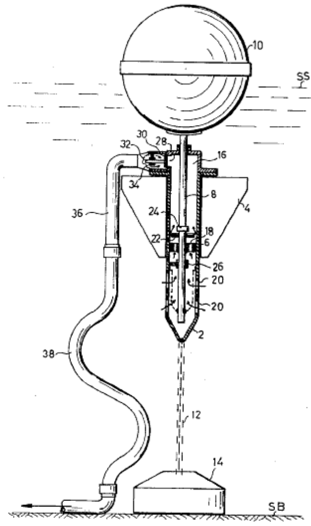
Transducer For Conversion of
Sea Water Energy
US Patent: 4,060,344, Nov. 29, 1977
Inventor: Fumio Ootsu, Japan



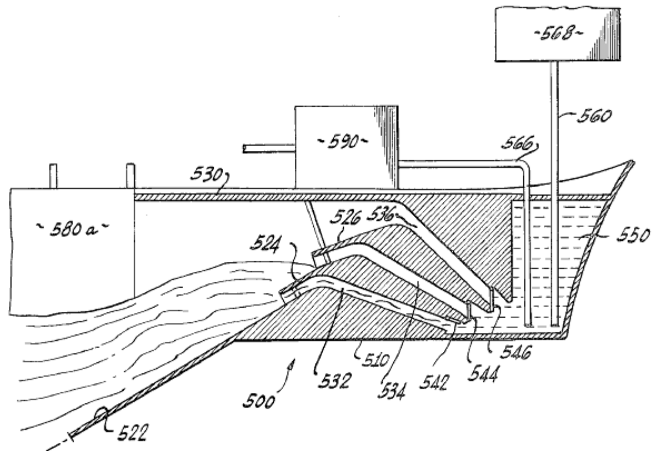
Transducer for Conversion of
Tidal Current Energy
US Patent: 4,071,305, Jan. 31, 1978
Inventor: Fumio Ootsu, Japan



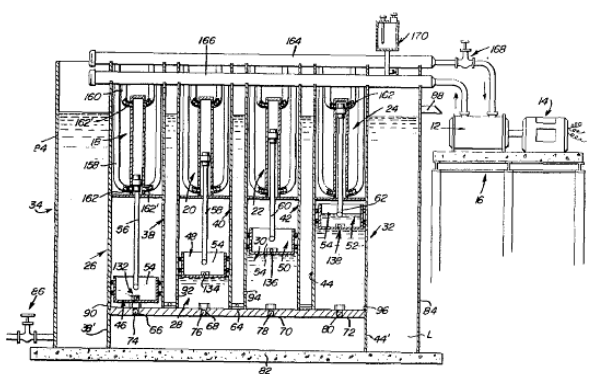
Dual Wave Motion Pump
US Patent: 4,076,464, Feb. 28, 1978
Inventor: Paul E. Pinney, NJ, USA



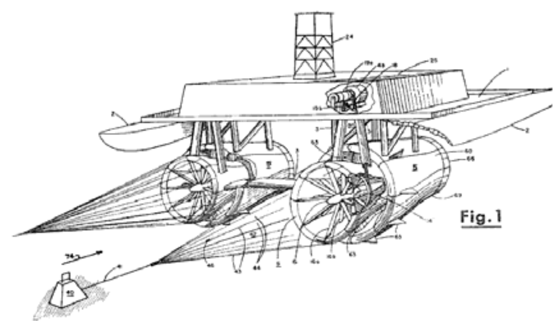
Wave Motor
US Patent: 4,076,463, Feb. 28, 1978
Inventor: Mordechai Welczer, Israel



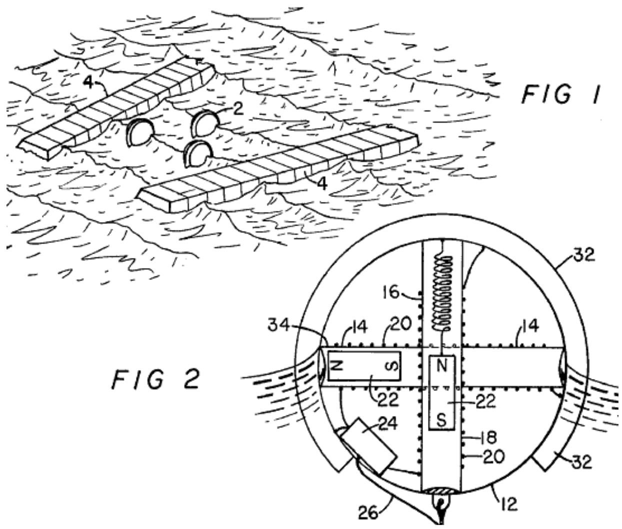
Sea Wave Energy Conversion
US Patent: 4,078,871, Mar. 14, 1978
Inventor: Clifford Perkins, CA, USA



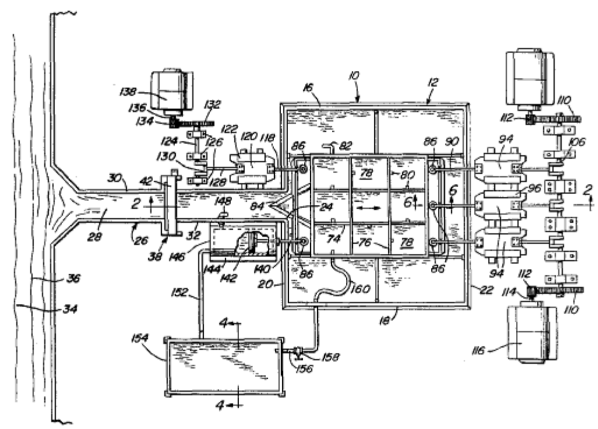
Apparatus and Method for Converting Hydrostatic Energy to Electrical Energy
US Patent: 4,083,186, April 11, 1978
Inventor: Andrew W. Jackson, AL, USA



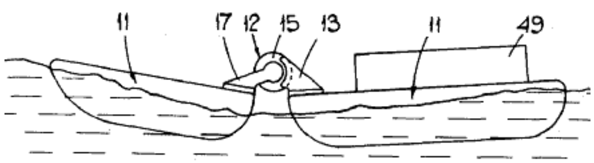
Turbine Wheel With Catenary Blades
US Patent: 4,095,918, June 20, 1978
Inventors: Mouton / Thompson, LA, USA



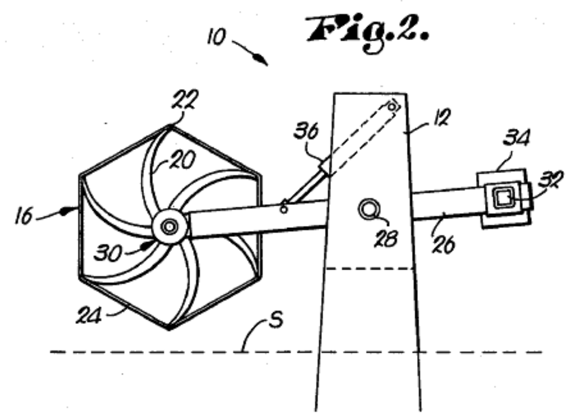
Wave Powered Electric Generator
US Patent: 4,110,630, Aug. 29, 1978
Inventor: Frank J. Hendel, CA, USA



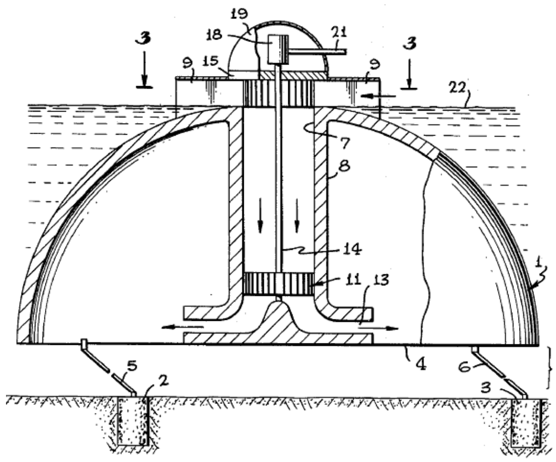
Wave Motor
US Patent: 4,108,579, August 1978
Inventor: Antero & Estrella Martinez
Dominican Republic



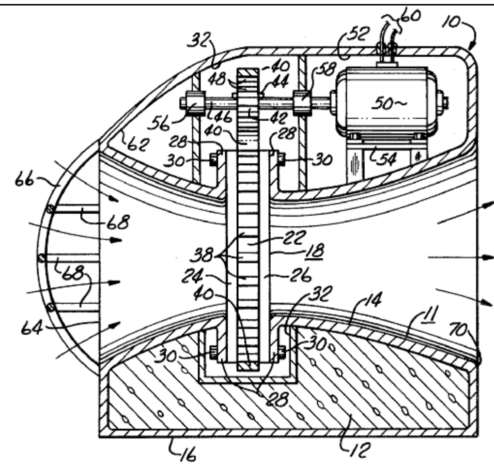
Energy Conversion Systems
US Patent: 4,118,932, Oct. 1978
Assignee: Lucas Industries, England



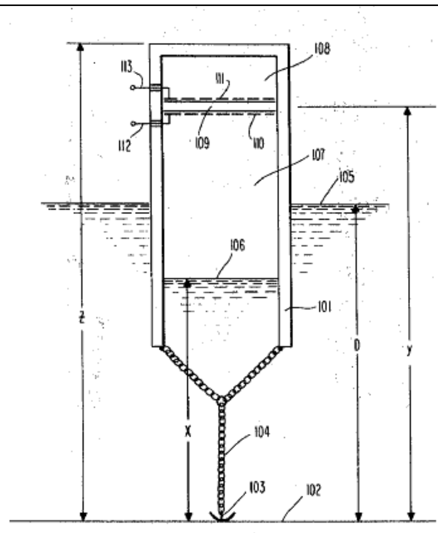
Oceanic Wave Powered Prime Mover
US Patent: 4,137,005. Jan.30, 1979
Inventor: Walter Comstock, KS, USA



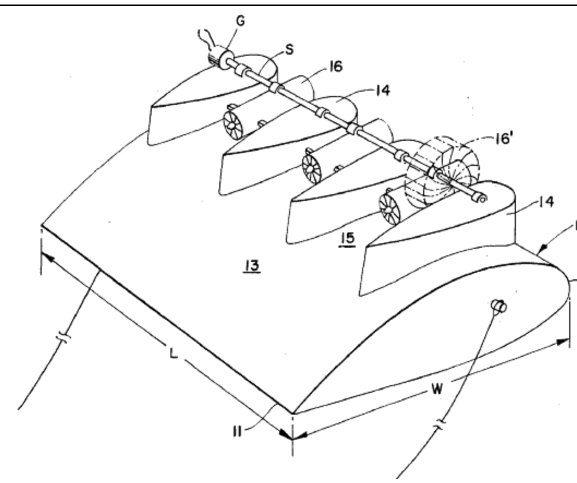
Wave Powered Motor
US Patent: 4,152,895, May 1979
Assignee: Lockheed Corporation, CA, USA



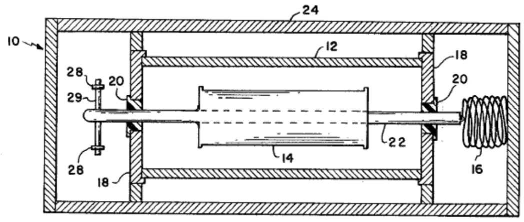
Understream Turbine Plant
US Patent: 4,163,904, August 7, 1979
Inventor: L. Skendrovic, PA, USA



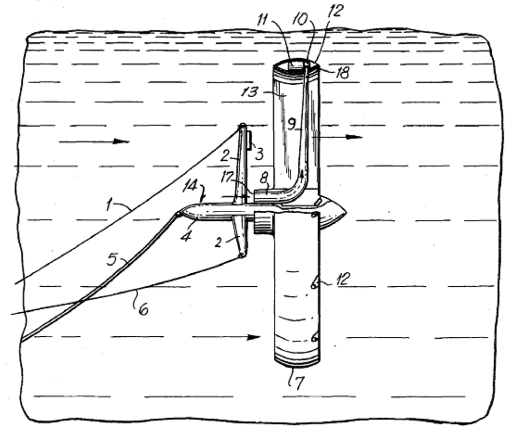
Process for Conversion of Ocean Wave Energy into Electric Power and Apparatus
US Patent: 4,178,517, Dec. 11, 1979
Assignee: Temple University, USA



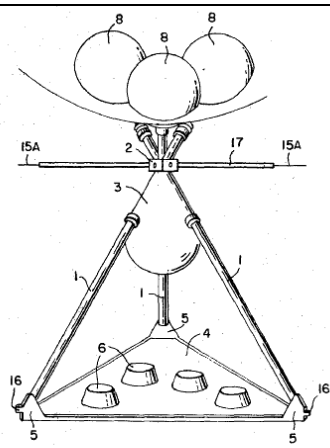
Method and Apparatus for obtaining useful work from Wave Energy
US Patent: 4,179,886, Dec. 25, 1979
Inventor: Juniro Tsubota, Japan



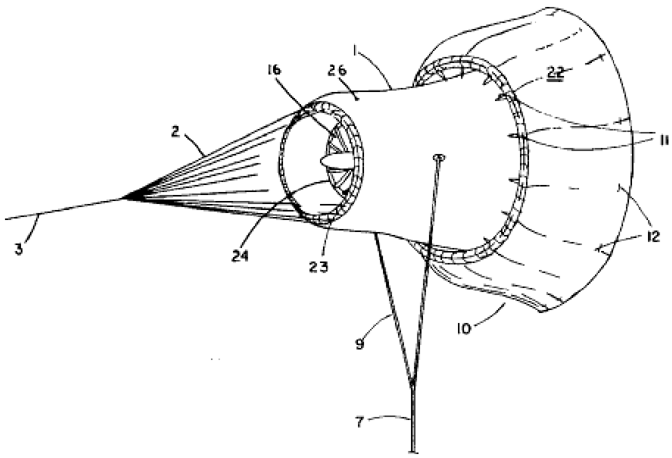
Natural Turbulence Electrical Power Generator
US Patent: 4,191,893, March 4, 1980
Assignee: USA on behalf of NASA



Hydro-electric Generator
US Patent: 4,205,943, June 1980
Inventor: Philippe Vauthier, MD, USA

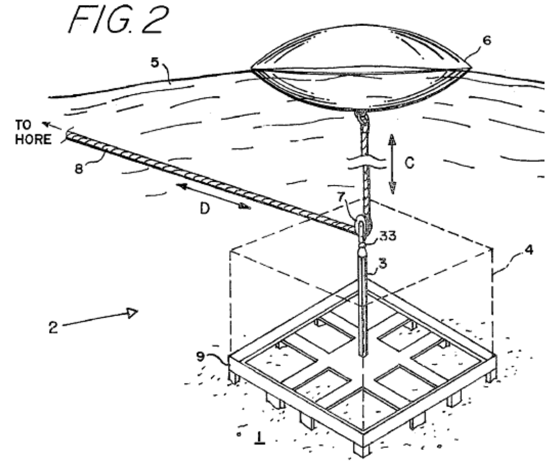


Ocean Wave Energy Converter
US Patent 4,232,230, June 14, 1980
Inventor: Foerd Ames, NY, USA

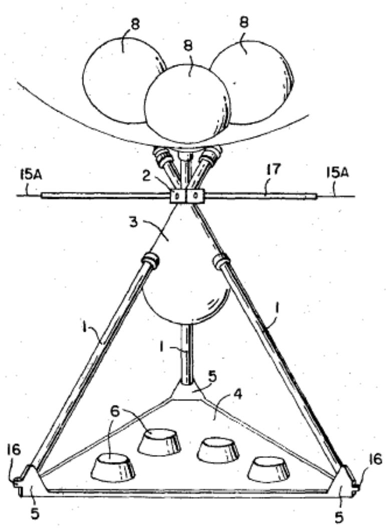


Submarine Turbine Power Plant
US Patent: 4,219,303, Aug. 26, 1980
Invventors: Mouton & Thompson, LA/ PA USA

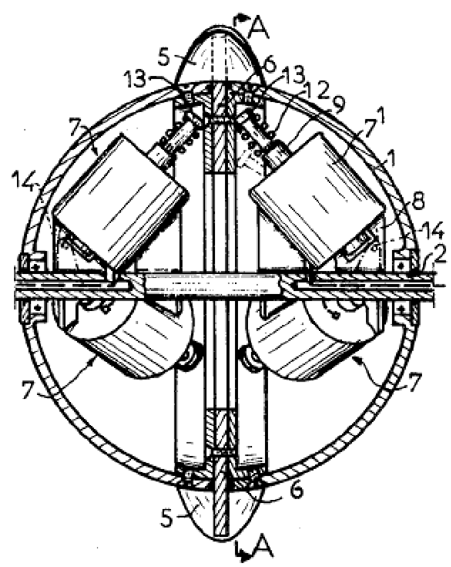
FIG. 2



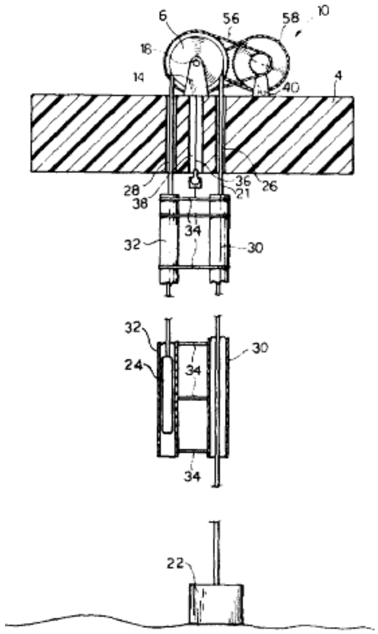
Wave Motion Apparatus
US Patent: 4,228,360, October 14, 1980
Inventor: Pablo Navarro, FL, USA



Ocean Wave Energy Converter
US Patent: 4,232,230, Nov. 4, 1980
Inventor: Foerd Ames, NY, USA

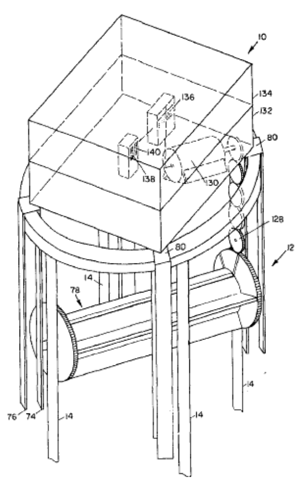


Floating Electric Generator Using the Driving Energy of Water
US Patent: 4,239,976, Dec. 16, 1980
Inventor: Louis-Jean Collard, France

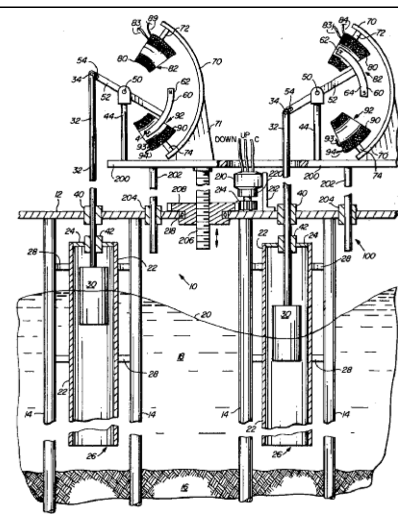


Device for Converting Sea Wave Energy into Electrical Energy
US Patent: 4,242,593, Dec. 30, 1980
Inventor: Quilico, & Troya, Italy

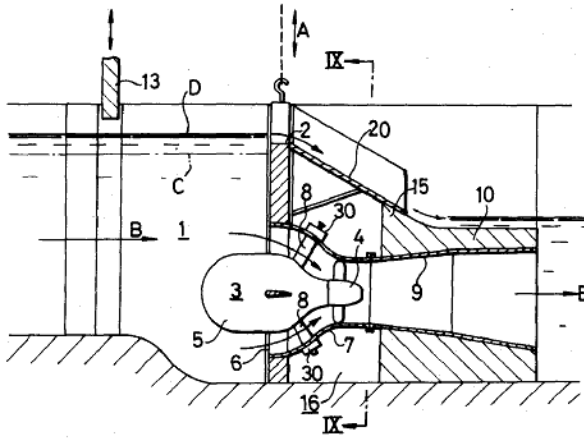
1981-1985



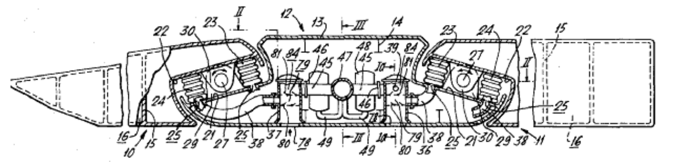
Apparatus for the Exploitation of Underwater Currents for the Production
of Electrical Energy
US Patent: 4,256,970, Mar. 17,1981
Inventor: Osvaldo Tomassini, Italy



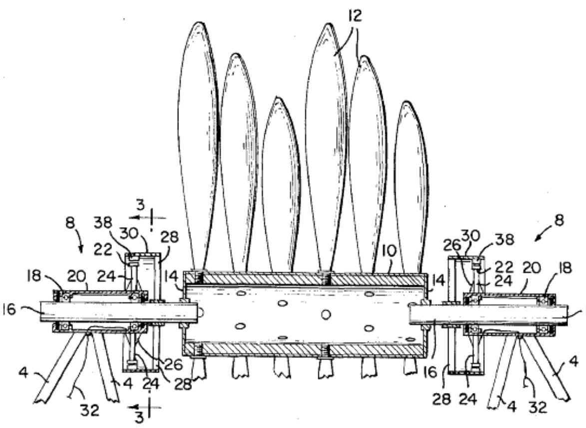
Wave Operated Electrical Generation System
US Patent: 4,260,901, April 7, 1981
Inventor: David Woodbridge, MD, USA



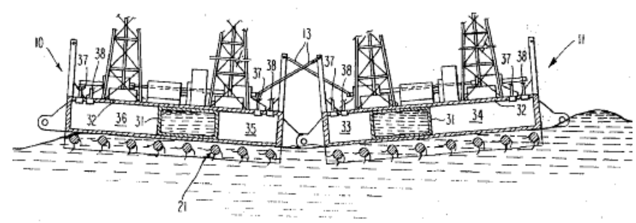
Electric Power Generation Equipment Incorporating Bulb Turbine- Generator
US Patent: 4,289,971, Sept. 15, 1981
Assignee: Fuji Electric, Japan



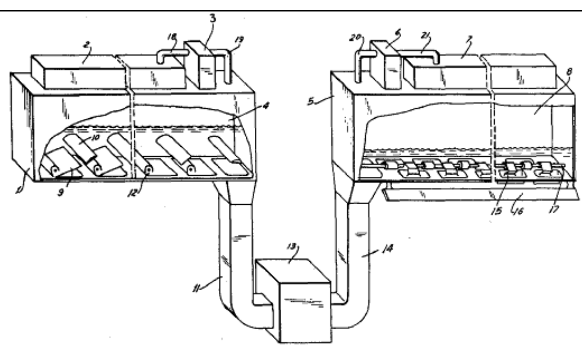
Devices for Extracting Energy from Waves
US Patent: 4,289,455, Sept. 15, 1981
Assignee: Secretary of State for Her Brittanic Majesty's Government of the UK

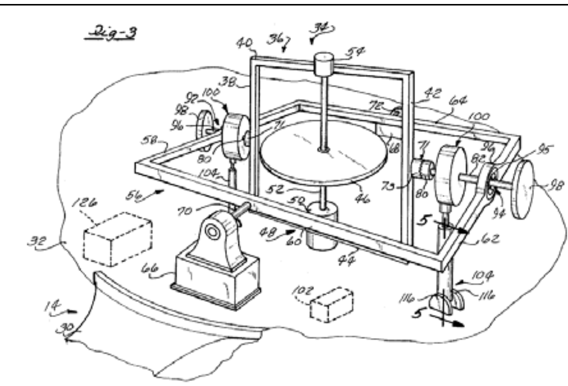


Underwater Slow Current Turbo Generator
US Patent: 4,306,157, Dec. 15, 1981
Inventor: Lazar Wracsaricht, WA, USA



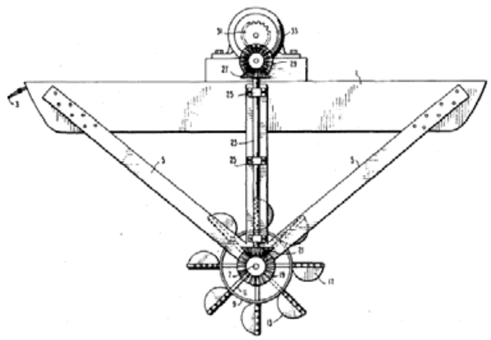
Floating Power Generation Assemblies and Methods
US Patent: 4,316,704, Feb. 1982
Inventor: Peter Heidt, NJ, USA



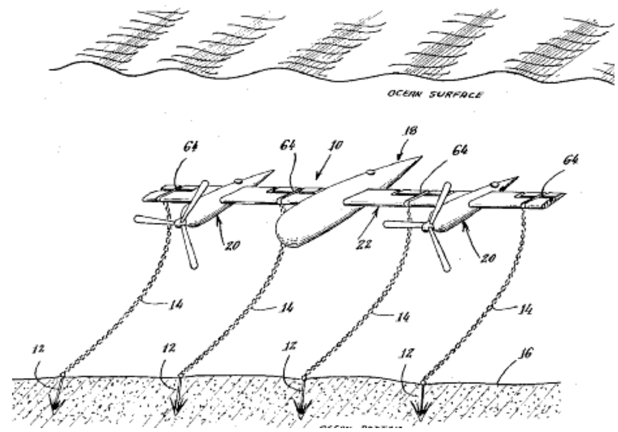


Sea and Ocean Wave Energy Converter
US Patent: 4,345,434, Aug. 24, 1982
Assignee: Institute Za Yadreni Izslednania I Yadrena Energetica – Bulgaria

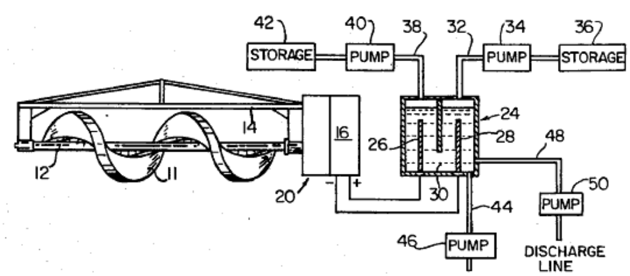
Mechanism for Generating Power from Wave Motion on a body of water
US Patent: 4,352,023, Sept. 28, 1982
Inventors: H. and G. Sachs, MI, USA



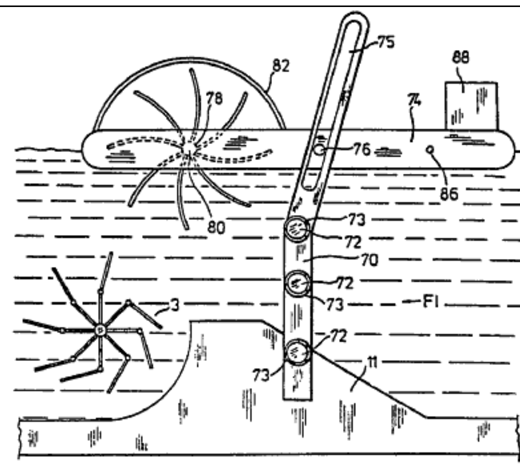
Ocean Wave Energy Converter
US Patent: 4,359,868, Nov. 23, 1982
Inventor: David M. Slonim, FL, USA



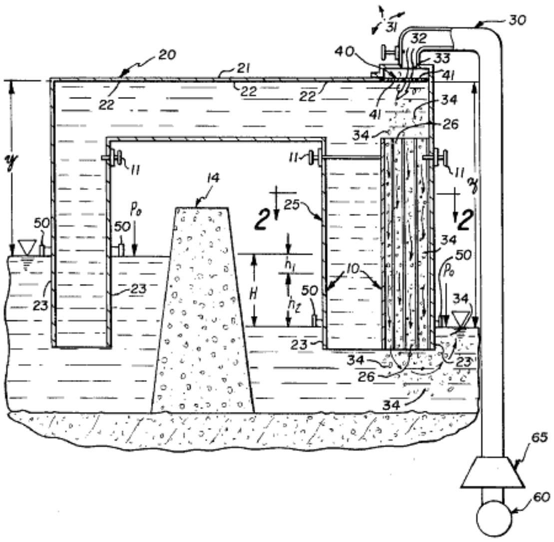
Underwater Power Generator
US Patent: 4,383,182, May 10, 1983
Inventor: Wallace Bowley, CT, USA



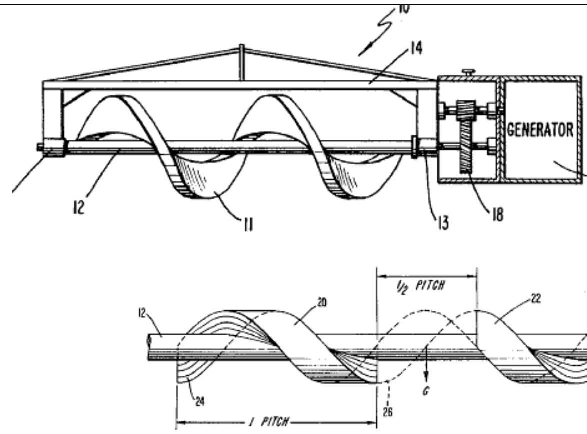
Apparatus for Storing the energy of Ocean Waves
US Patent: 4,384,212, May 17, 1983
Assignee: Laitram Corp. LA, USA



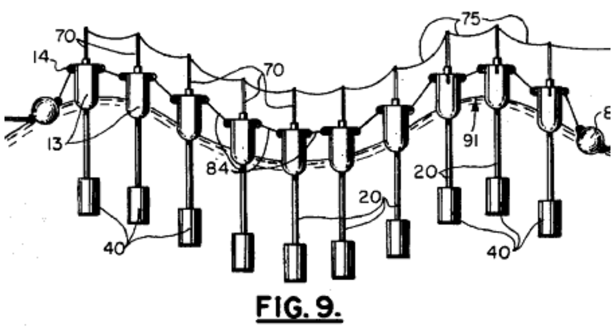
Underwater Turbine Device with Hinged Collapsible Blades
US Patent 4,383,797, May 17, 1983
Inventor: Edmund Lee, Ontario, Canada



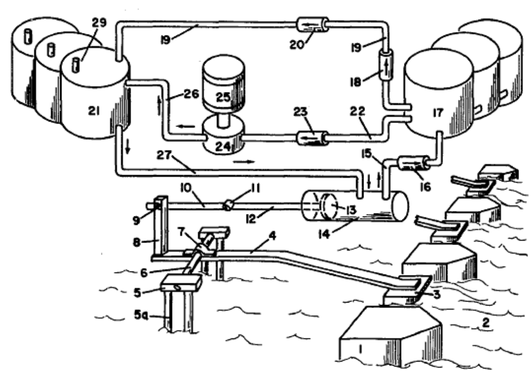
Tidal Power Generation Using Atmospheric Pressure
US Patent: 4,396,842, Aug. 2, 1983
Inventor: Bonghan Jhun, Korea



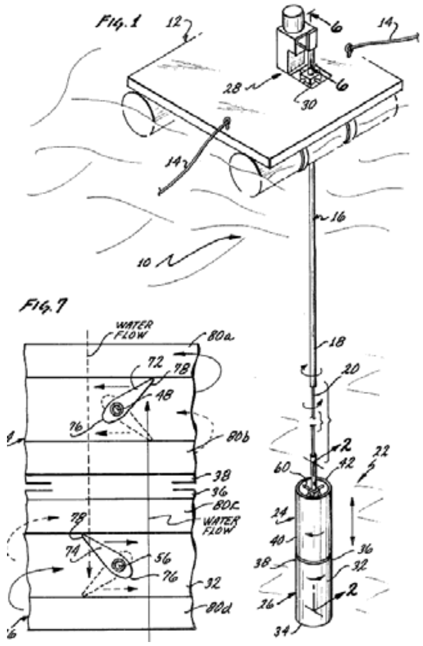
Wave Energy Converter
US Patent: 4,412,417, Nov. 1983
Assignee: Tracor Hydronautics, MD, USA



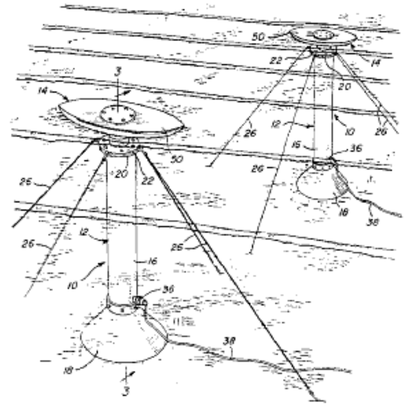
Wave Response Generator
US Patent: 4,447,740, May 8, 1984
Inventor: Louis Heck, LA, USA



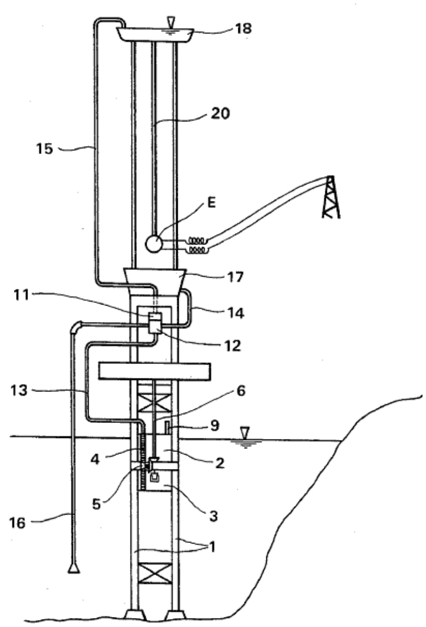
Method of Converting Ocean Energy Action Into Electrical Energy
US Patent: 4,454,429, June 12, 1984
Inventor: Frank Buonome, CT, USA



Apparatus for Harvesting Wave Energy
US Patent: 4,462,211, July 31, 1984
Inventor: Hal Linderfelt, CA, USA



Wave Activated Generator
US Patent: 4,539,485, Sep. 3, 1985
Inventor: V. Neuenschwander, NM, USA



Method and Apparatus for Tidal Electric Power
Generation Using The Buoyancy Energy of the Tide
US Patent: 4,544,840, October, 1, 1985
Inventor: In K. Choi, Korea

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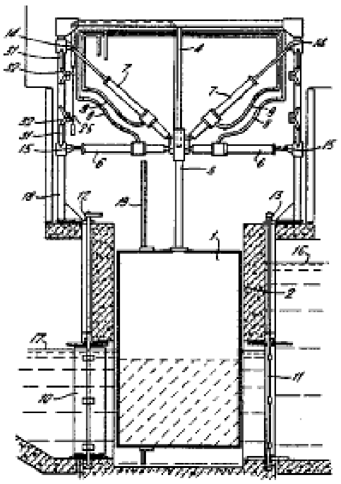
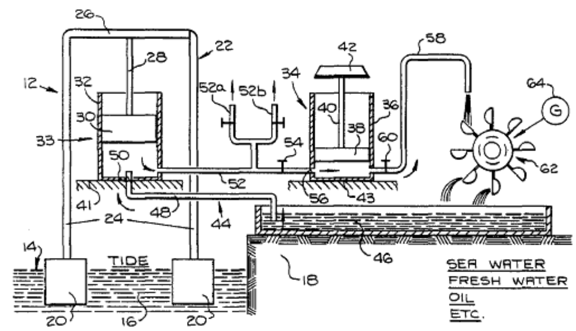
<td>
Water Engine
US Patent: 4,586,333, May 6, 1986
Assignee: Aur Hydropower, Ltd.</td>
<td>

Tidal Energy System
US Patent: 4,598,211, July 1, 1986
Inventor: John Koruthu, Kuwait</td>
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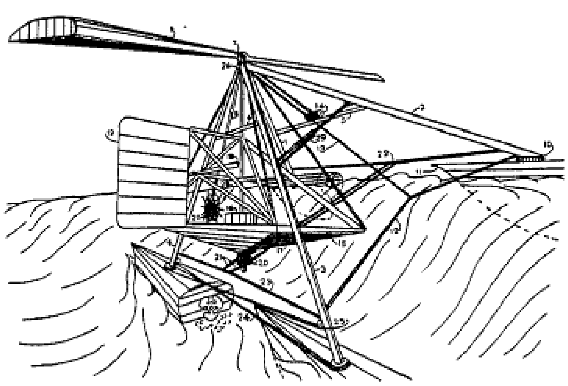
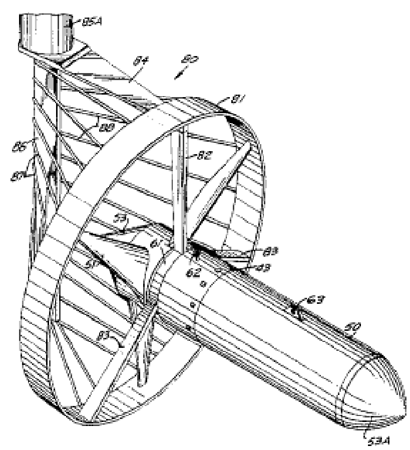
<td>
Ocean Wave Energy Converting Vessel
US Patent: 4,608,497, Aug. 26, 1986
Inventor: Peter Boyce, NJ, USA</td>
<td>
Kinetic Hydro Energy Conversion System
US Patent: 4,613,279, Sept. 23, 1986
Assignee: Riverside Energy Tec. NY, USA</td>
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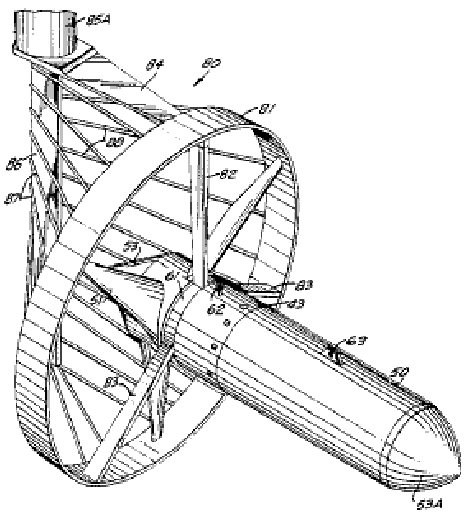
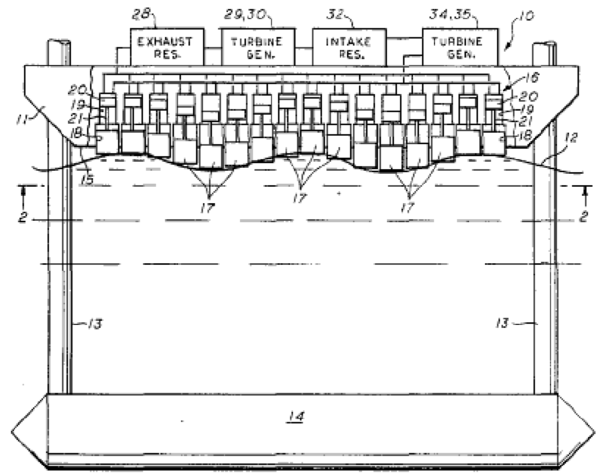
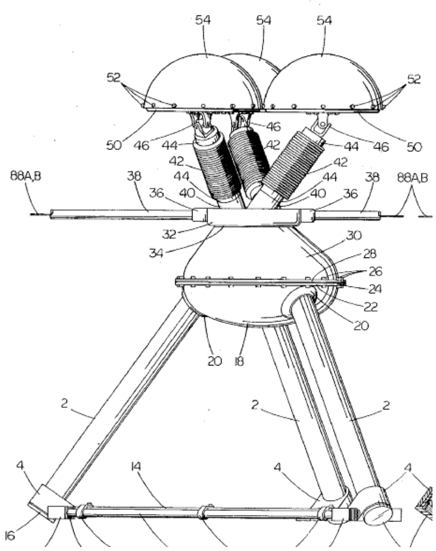


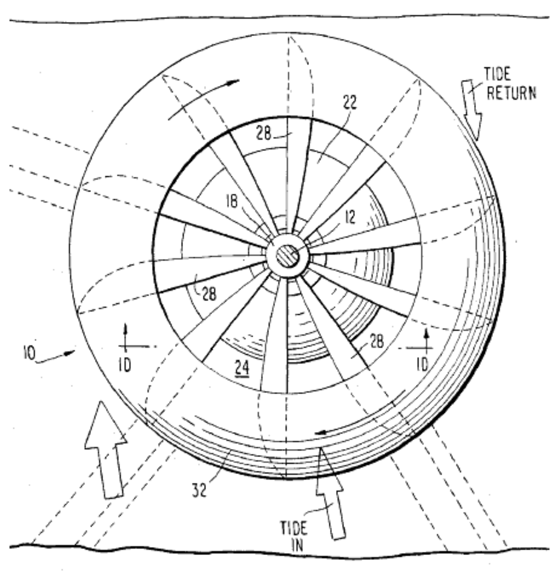
Riverside Energy Technology
Kinetic Hydro Energy Conversion System
US Patent: 4,613,279, Sep. 23, 1986
Inventors: Corren & Miller, NY, USA



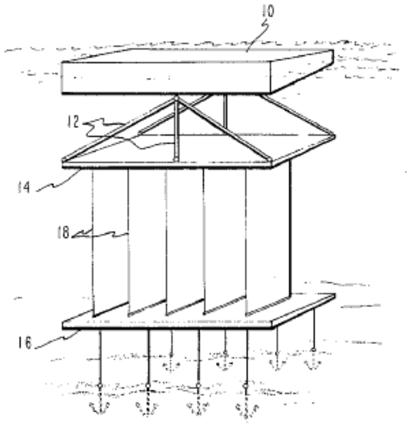
Wave Action Power Generator Platform
US Patent: 4,622,473, Nov. 1986
Inventor: Adolph Curry, AK, USA



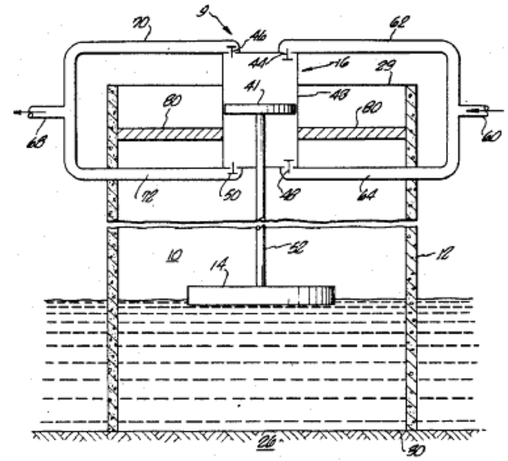
Ocean Wave Energy Converter
US Patent: 4,672,222, June 9, 1987
Inventor: P. Foerd Ames, RI, USA



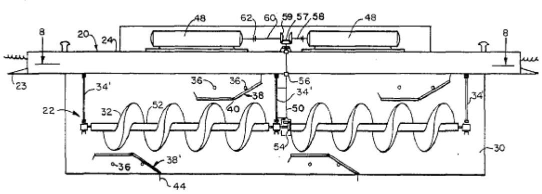
Tide Turbine
US Patent: 4,686,376, Aug. 11, 1987
Inventor: Philip Retz, Washington, DC



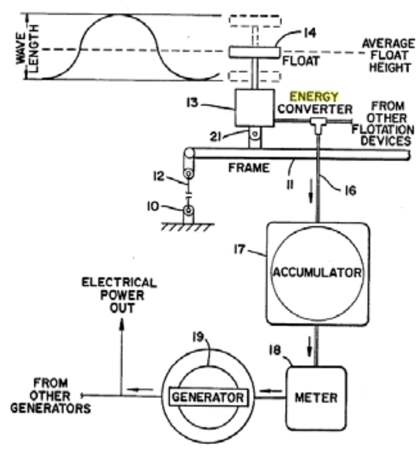
Ocean Wave Energy Conversion Using Piezoelectric Material Members
US Patent: 4,685,296, August 11, 1987
Inventor: Joseph Burns, NJ, USA



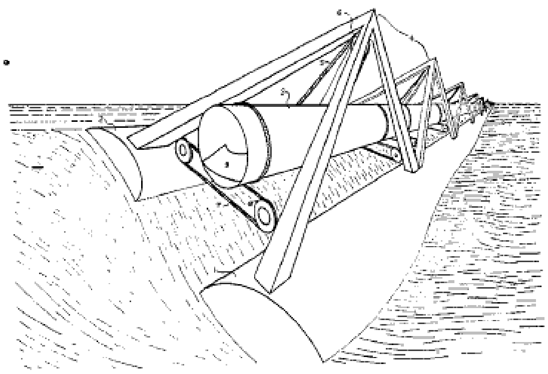
Wave Power Converter
US Patent: 4,698,969, October 13, 1987
Assignee: Wave Power Industries, CA, USA



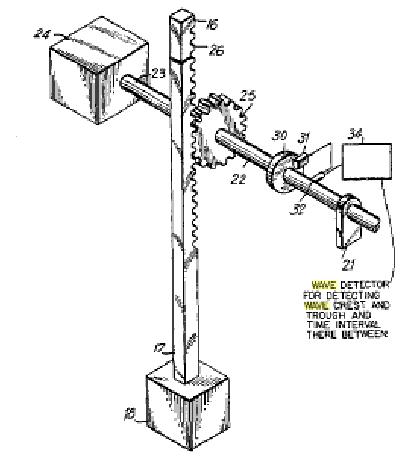
Tidal and River Turbine
US Patent: 4,717,832, Jan 5, 1988
Inventor: Charles Harris, MD, USA



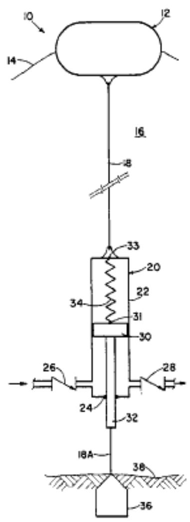
Wave Energy Engine
US Patent: 4,742,241, May 3, 1988
Inventor: Kenneth P. Melvin, CA, USA



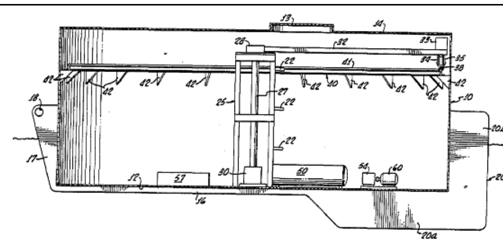
Ocean Wave Energy Extracting Erosion Reversal and Power Generation System
US Patent: 4,748,338, May 31, 1988
Inventor: Peter Boyce, NJ,



Ocean Wave Energy Device
US Patent: 4,599,858, July 15, 1988
Inventors: J. La Stella & Tornabene, NY, USA

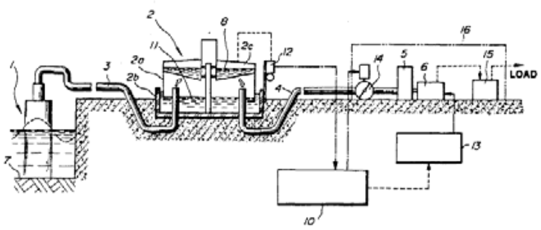


Float Type Wave Energy Extraction Apparatus and Method
US Patent: 4,754,157, June 28, 1988
Inventor: Tom Windle, OK, USA

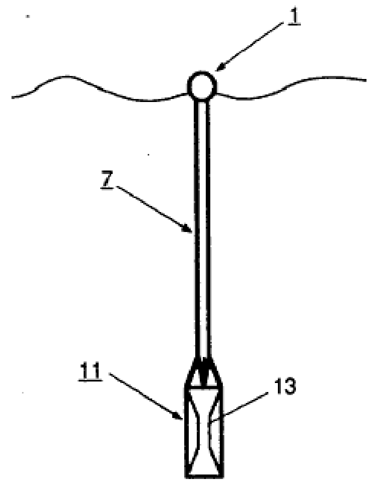


Wave Action Power Generator
US Patent: 4,843,250, June 27, 1989
Assignee: JSS Scientific Corp., CA, USA

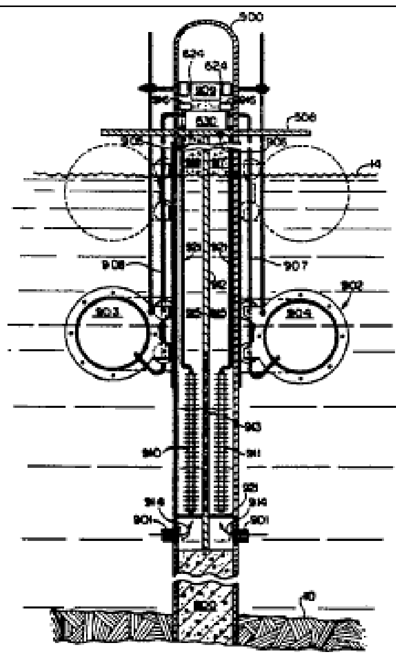
1991-1995



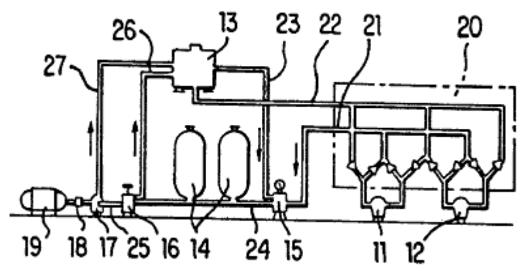
Method and Apparatus for Generating Electricity Using Wave Energy
US Patent: 5,027,000, June 25, 1991
Assignee: Takenaka Corp., Japan



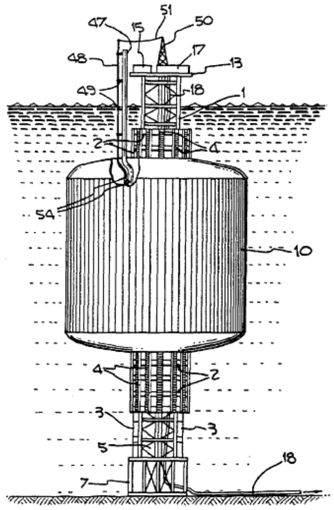
Ocean Wave Energy Conversion Device
US Patent: 5,136,173, August 1992
Assignee: Scientific Applications & Research Associates, Inc. CA, USA



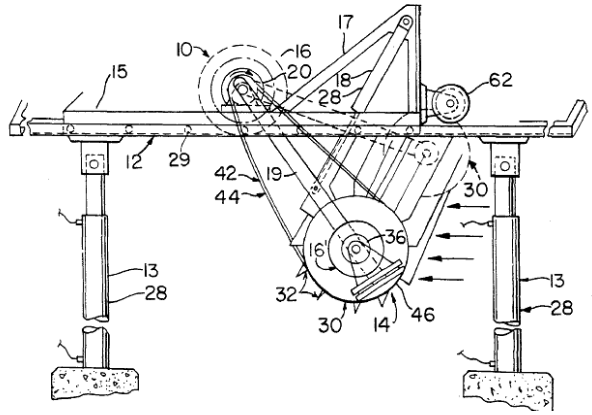
Wave Power Collection Apparatus
US Patent: 5,167,786, Dec. 1, 1992
Inventor: William Eberle, TX, USA



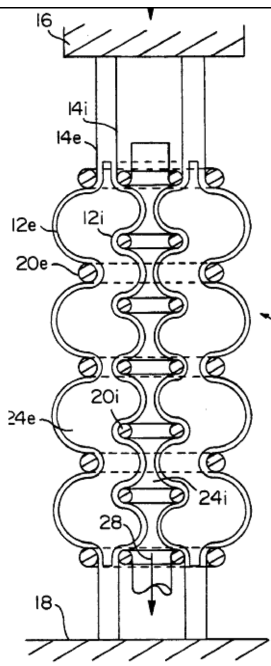
Water Current Energy Converter
US Patent: 5,281,856, Jan. 25 1994
Inventor: Tibor Kenderi, Hungary



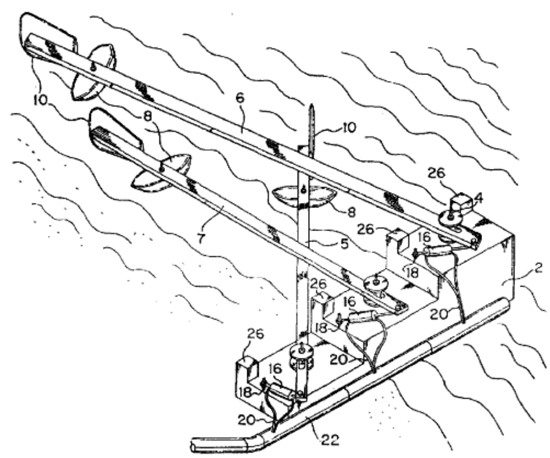
System for Undersea Wave generation of Electric Power
US Patent: 5,324,988, Jan. 28, 1994
Inventor: Edwin Newman, CA, USA



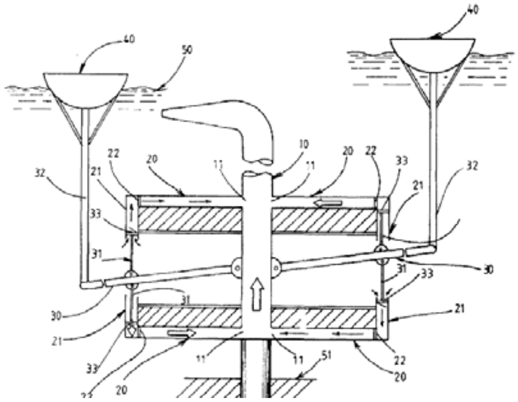
Equipment to Extract Ocean Wave Power
US Patent: 5,311,064, May 10, 1994
Inventor: Bogumil Kumbatovic, NY, USA



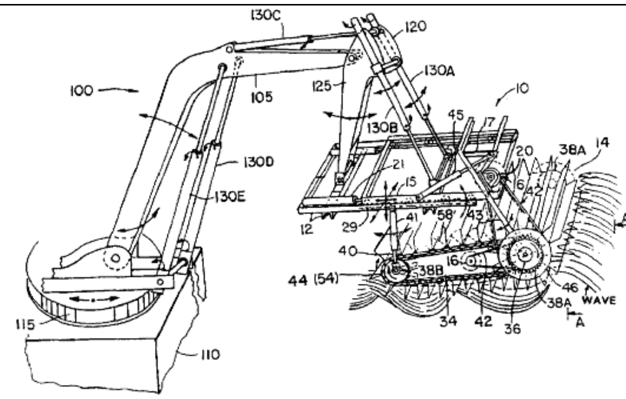
Device for Generation Hydrodynamic Power
US Patent: 5,329,497, Jul 12, 1994
Inventor: B. & M. Previsic, Switzerland



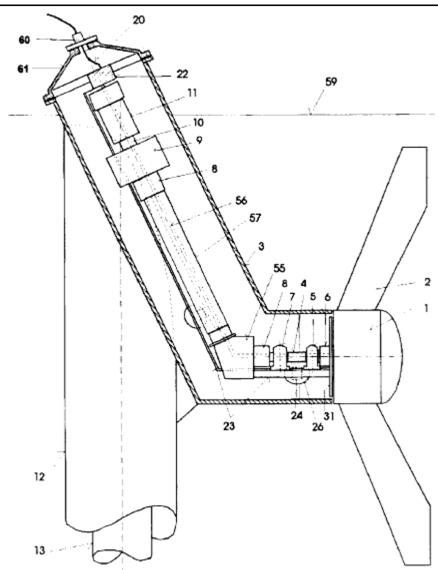
Ocean Wave Energy Conversion System
US Patent: 5,708,305, Jan 13, 1998
Inventor: Douglas Wolfe, VA, USA



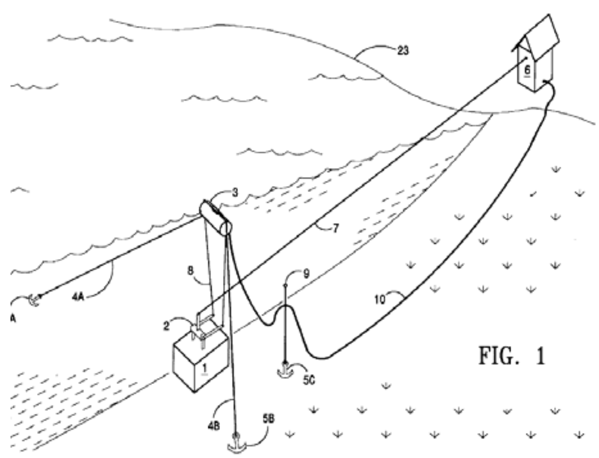
Power Drive System For Converting Natural Potential Energy Into A Driving Power To Drive a Power Generator
US Patent: 5,710,464, Jan. 20, 1998
Inventors: Kao, Kao and Lee, Taiwan



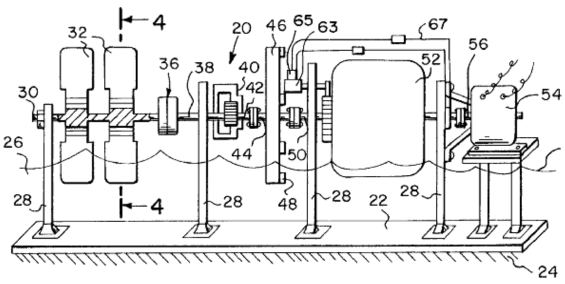
Equipment to extract ocean wave power
US Patent: 5,789,826, Aug. 4, 1998
Inventor: B. Kumbatovic, NY, USA



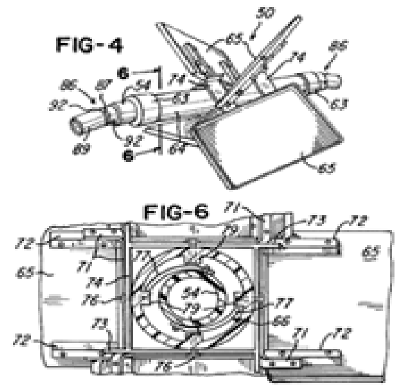
Under Water Hydro Turbine Energy Generator Design
US Patent: 5,798,572, Aug. 25, 1998
Kalman Lehoczky, FL USA



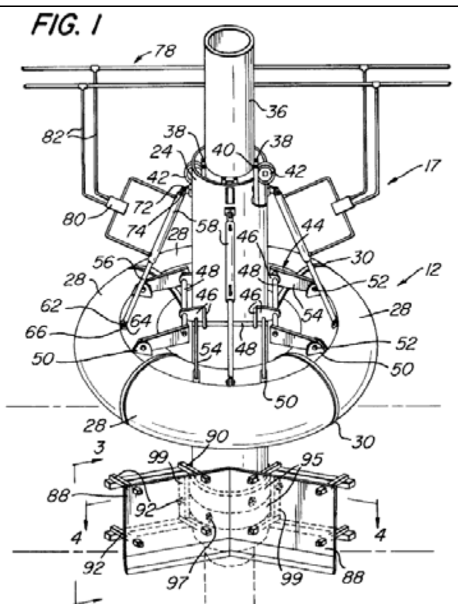
Ocean Wave Energy Conversion Device
US Patent: 5,808,368 , Sept. 15, 1998
Inventor: Clifford Brown
Washington, DC, USA



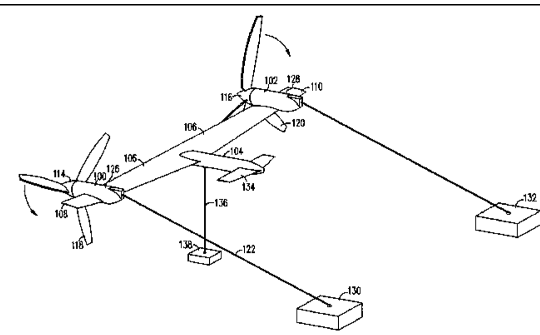
Sea / River Powered Power Plant
US Patent 5,834,853, Nov. 10, 1998
Inventor: Rene Ruiz, TX, USA



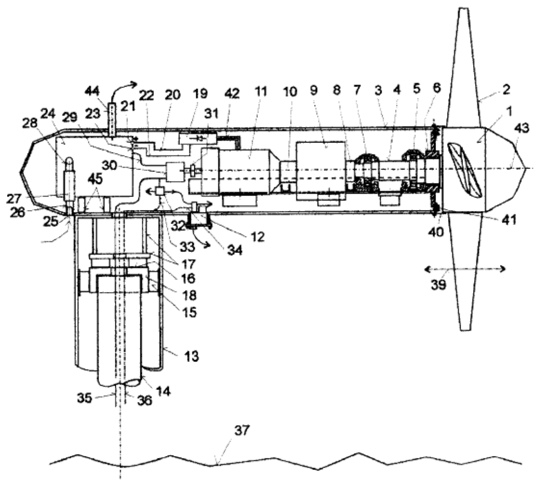
Swort International
US Patent 5,946,909, Sep. 7, 1999
Roman Szpur, OH, USA



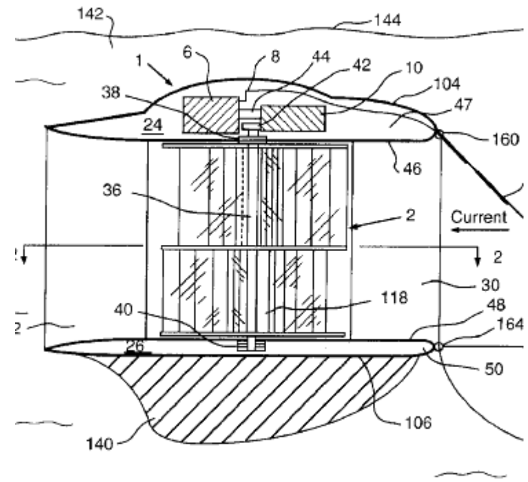
Wave Enhancer For A System For Producing Electricity From Ocean Waves
US Patent: 5,986,349, Nov. 16, 1999
Inventor: William Eberle, TX, USA



Dehlsen Associates, LLC
Method of controlling operating depth of electricity generating device having tethered current driven turbine
US Patent: 6091,161, Jul. 18, 2000
Inventors: James G. & James B. Dehlsen & Geoffrey Deane, CA, USA

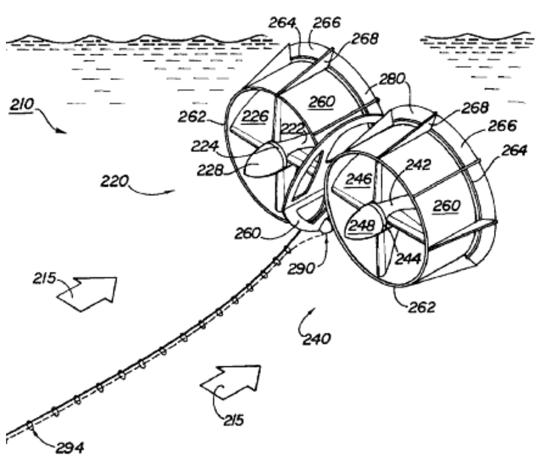


Underwater Hydro-Turbine for Hydrogen Production
US Patent 6,104,097, Aug. 15, 2000
Inventor: Kalmen Leboczy, FL, USA

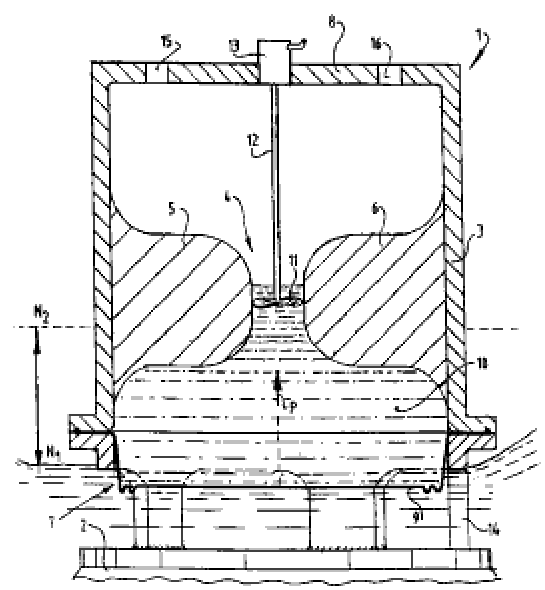


Submersible Apparatus for Generating Electricity
US Patent: 6,109,863, Aug. 29,2000
Inventor: Larry Milliken, PA, USA

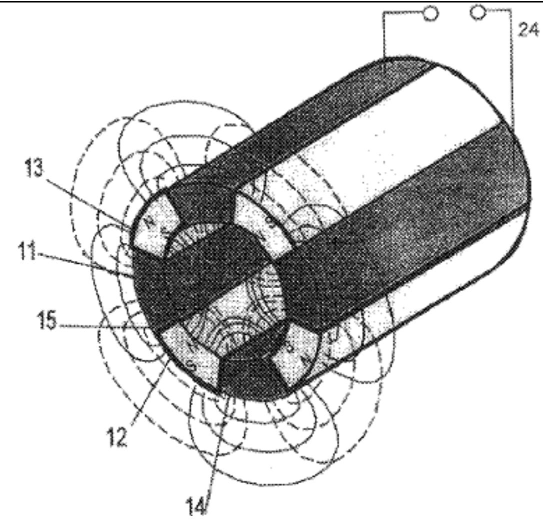
2001-current



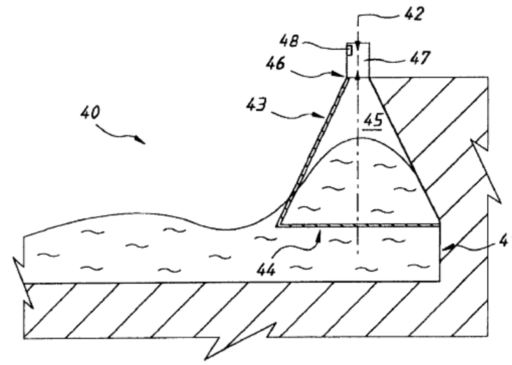
Dual Hydroturbine Unit
US Patent: 6,168,373 B1, January 2, 2001
Inventor: Philippe Vauthier, MD, USA



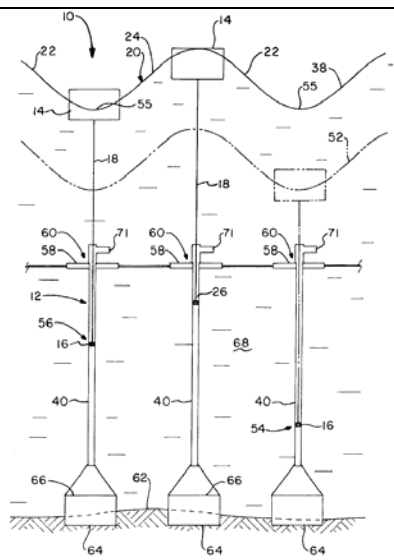
Apparatus for the Conversion of Energy from the Vertical Movement of Seawater
US Patent: 6,216,455 B1, Apr. 2001
Inventors: Doleh & Lock, Dubai, UAE



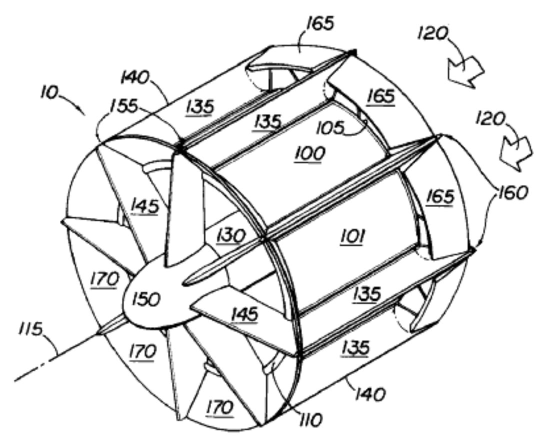
Magneto Hydro Dynamical Tidal and Ocean Current Converter
US Patent: 6,301,406 B1, Oct. 30, 2001
Inventor: Jacob Van Berkel
Entry-Technology, Netherlands



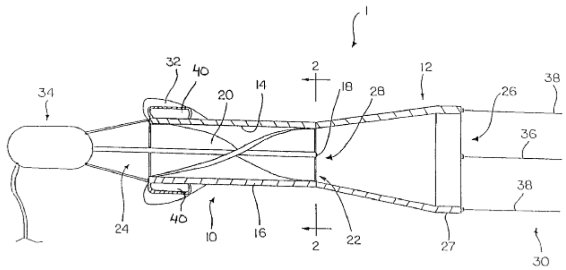
Ocean Wave Energy Extraction
US Patent: 6,360,534 B1, Mar. 26, 2002
Assignee: Energetech, Pty, Australia



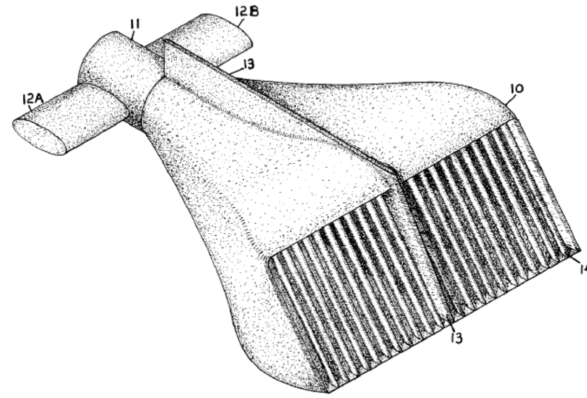
Hydro Electric Plant
US Patent: 6,388,342 B1, May 14, 2002
Inventor: Richard Vetterick Sr.& Jr. NY, USA



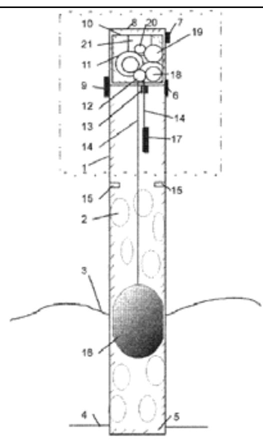
Bi-Directional Hydroturbine Assembly for Tidal Deployment
US Patent: 6,406,251, June 18, 2002
Inventor: Philippe Vauthier, MD, USA



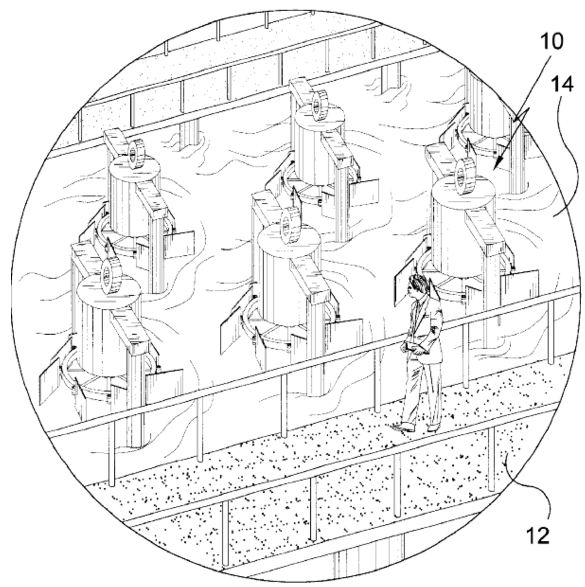
Hydro Turbine
US Patent: 6,409,466 B1, June 25, 2002
Inventor: John S. Lamont,
Winnipeg, Canada



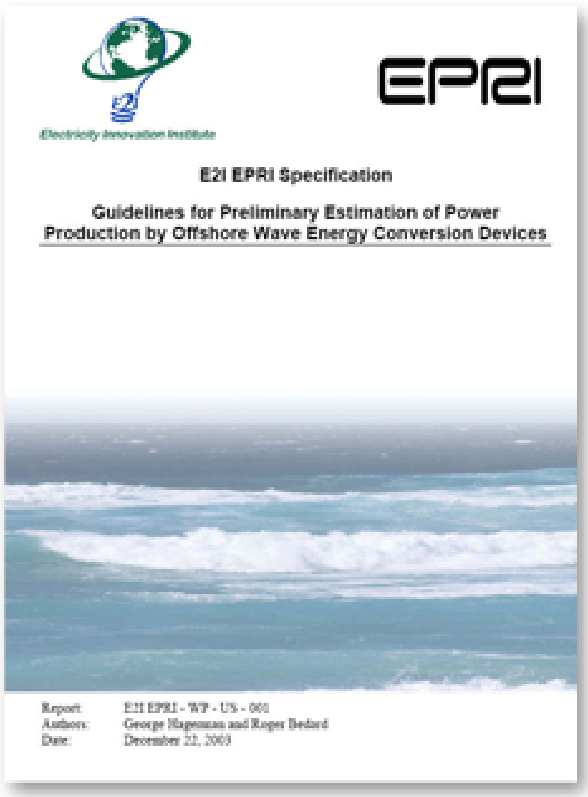
Hydrokinetic Generator
US Patent: 6,472,768 B1, Oct. 29, 2002
Inventor: Darwin Aldis Salls, FL, USA

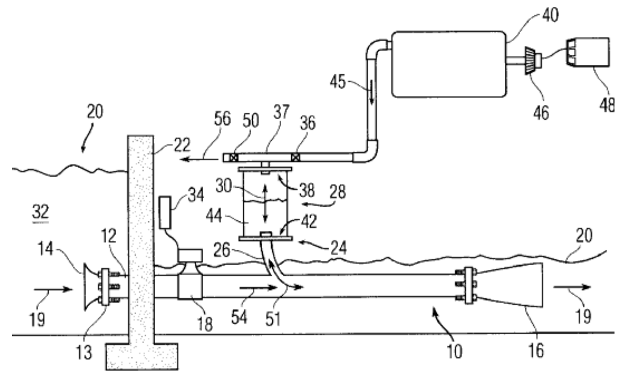


Able Technologies, LLC
Electricity Generating Wave Pipe
US Patent 6,476,512; Nov. 5, 2002
Inventor: Stanley Rutta, NJ, USA

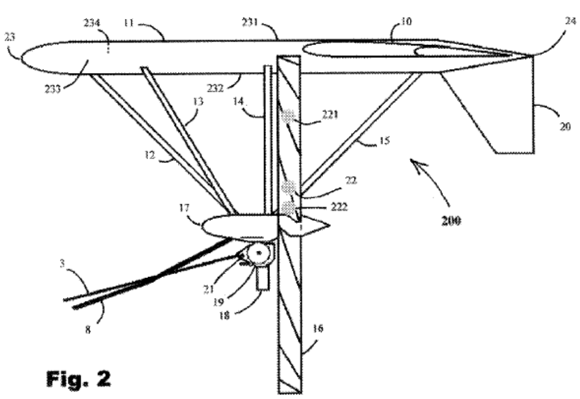


Water Wheel
US Patent: 6,499,939 B2, Dec. 31, 2002
Inventor: Eric E. Downing, WI, USA

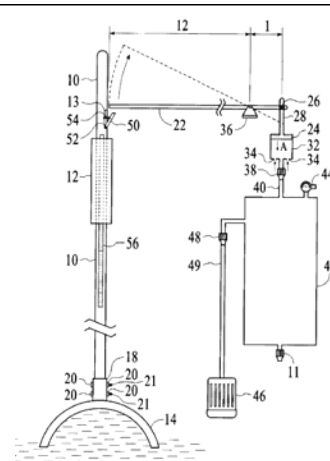




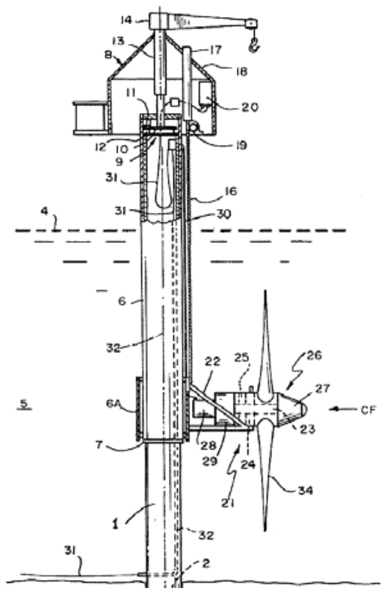
Hydropower conversion system
US Patent: 6,546,723, April 2003
Assignee: US of A, Sec. of Navy, DC, USA



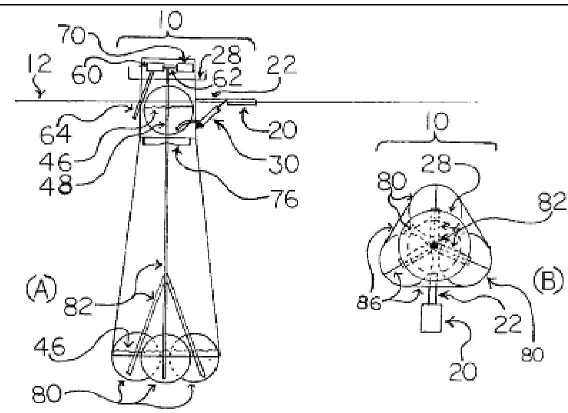
Submersible electrical power generating plant
US Patent: 6,531,788 B2, Mar. 11, 2003
Inventor: John, Robson, IL, USA



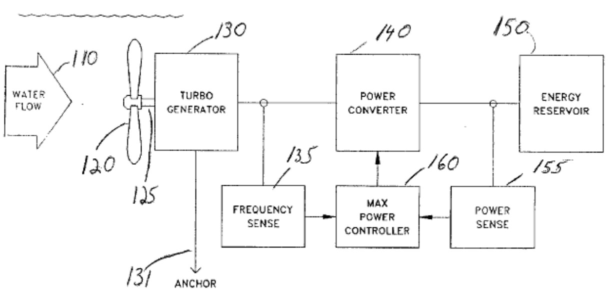
Tidal / Wave Compressed Air Electricity Generation
US Patent: 6,574,957 B2, June, 10, 2003
Inventor: Donald Brumfield, CA, USA



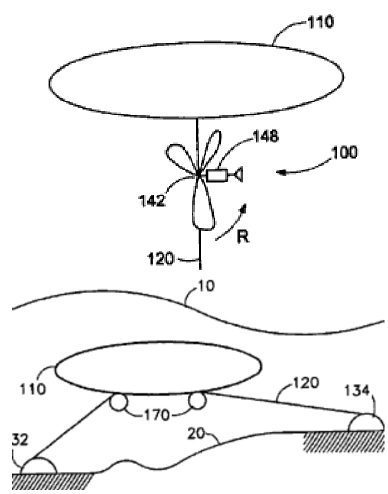
Water Current Turbine Sleeve Mounting
US Patent: 6,652,221, Nov. 2003
Inventor: Peter Praenkel, London, England



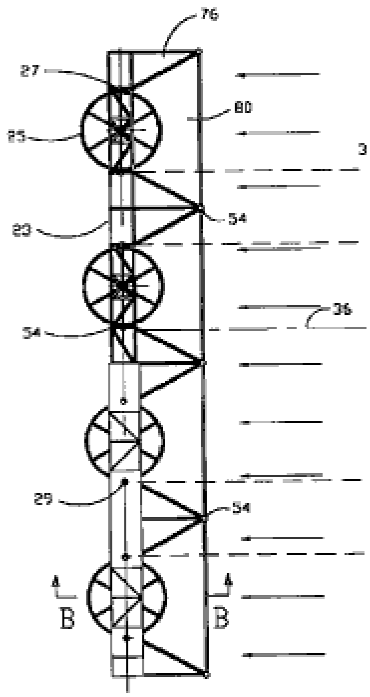
Ocean Wave Power Generator "Modular Power-Producing Network"
US Patent: 6,647,716 B2, Nov. 18, 2003
Inventor: Secil Boyd, HI, USA



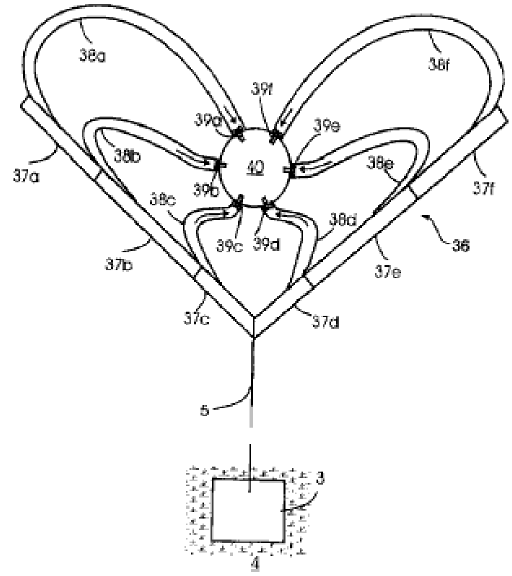
Apparatus and Method for Extracting Maximum Power from Flowing Water
US Patent: US2003/0218338 A1, Nov. 2003
Inventor: George O'Sullivan, PA, USA



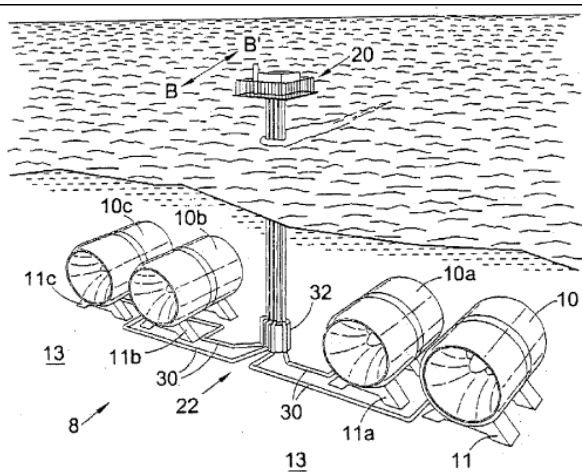
Method of and Apparatus for Wave Energy Conversion Using Float w/ Excess Buoyancy
US Patent 6,756,695 B2, June, 29, 2004
Assignee: Aerovironments Inc. CA, USA



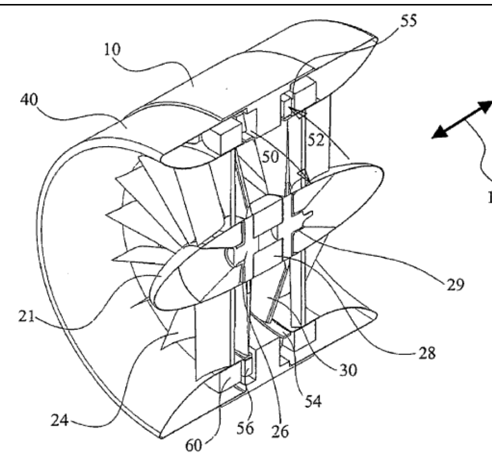
Installation for Harvesting Ocean Energy
US Patent: 6,856,036, Feb. 15, 2005
Inventor: Sidney Belinsky, FL, USA



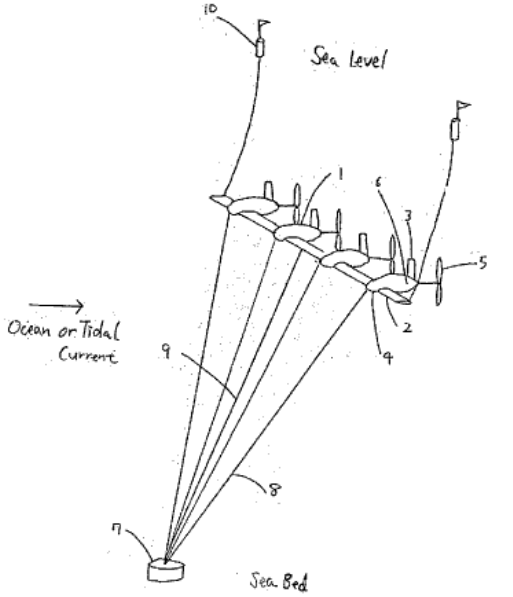
Plant for Utilizing the Energy In Sea Waves
US Patent: 6,527,504, B1, Mar. 4, 2005
Assignee: Waveplane Intl., Denmark



Power Generator and Turbine Unit
US Patent Ap. US 2005/0001432 A1
Inventors: Susman, R & D. Steward
Aberdeen, GB



Hydro Turbine Generator
US Patent Ap: US 2005/0285407 A1
Inventors: Davis, Grillos, Allison
WA, USA



Method Comprising Electricity Transmission, Hydrogen Production and it's transportation from Ocean and/or Tidal Current…
US Patent: US2005/0121917 A1, June 2005
Inventor: N. Kikuchi, CA, USA

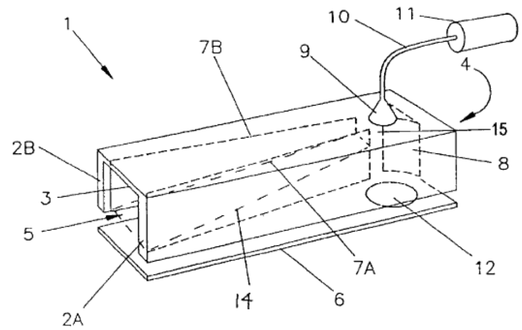
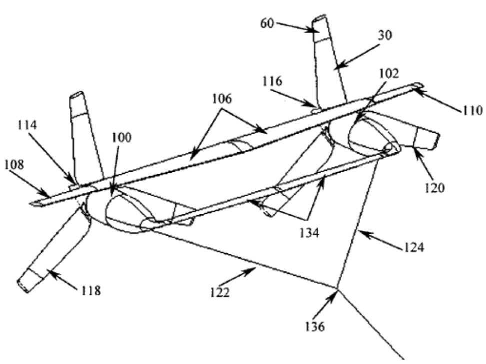
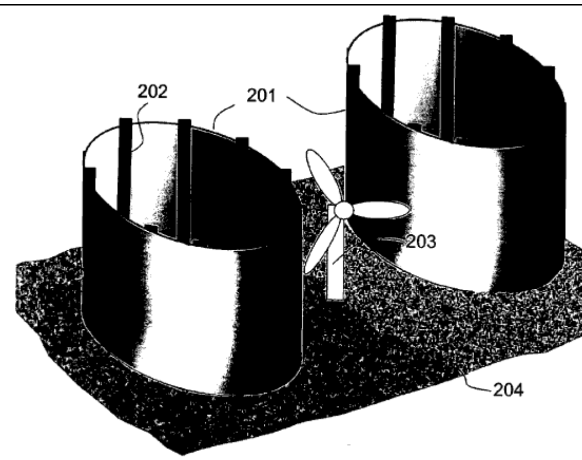


FIGURE 1

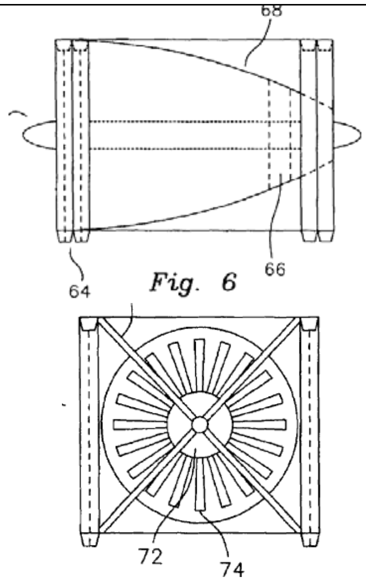
Apparatus for Deriving Energy from Waves
US Patent: 6,922,993 B2, Aug. 2, 2005
Inventor: John F. Kemp, England



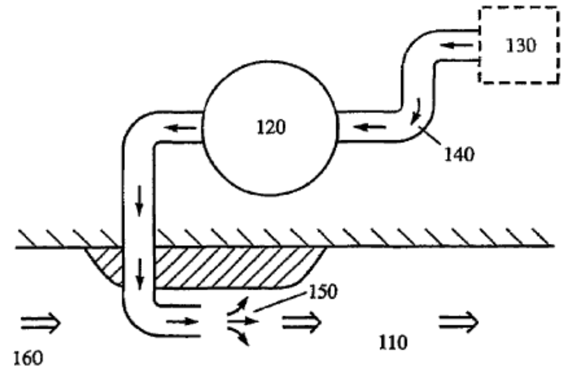
Mechanism for Extendable Rotor Blades for Power Generating Wind and Ocean Current Turbines and Means for Counter-balancing the Extendable Rotor Blade
US Patent: 6,923,622 B1, Aug 2, 2005
Assignee: Clipper Windpower USA



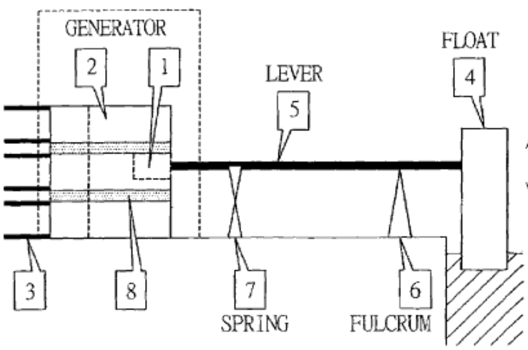
Tidal Current Accelerating Structure for Electrical Power Generation
US Patent Ap: US2005/0236843, Oct. 2005
Inventors: Roddier & Cermelli, CA, USA



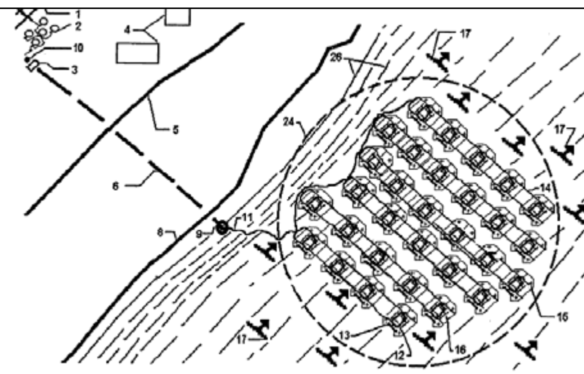
Machine and System for Power Generation through the movement of Water
US Patent 6,955,049 B2, Oct. 18, 2005
Inventor: Wayne F. Krouse, TX, USA



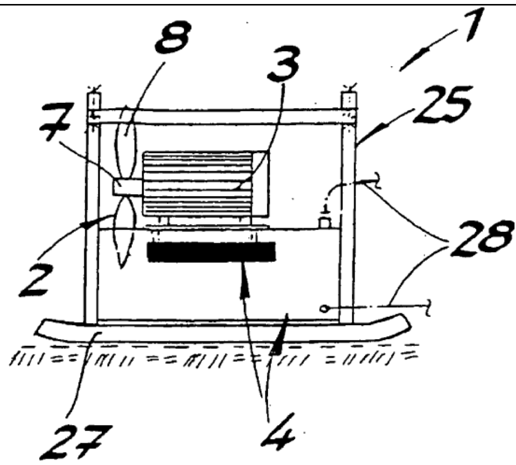
Extracting Power from a Fluid Flow
US Patent: 7,132,758 B2, Nov. 7, 2005
Inventors: Rochester, Pullen, Hassard
London, UK



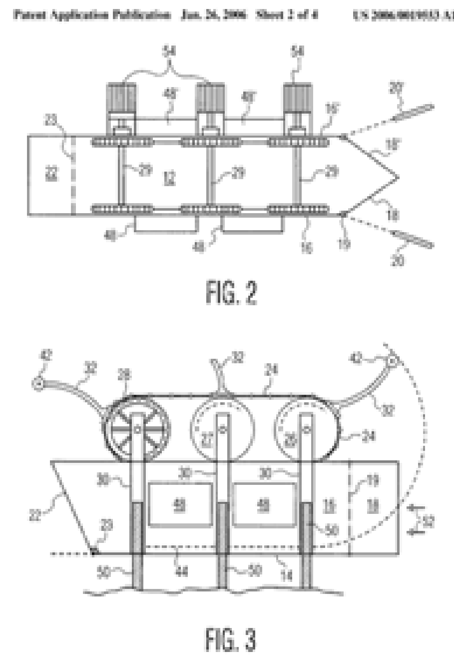
Apparatus For Converting Ocean Wave Energy Into Electric Power
US Patent: 7,012,340 B2, March 14,2006
Assignee: Kun Shan University, Taiwan



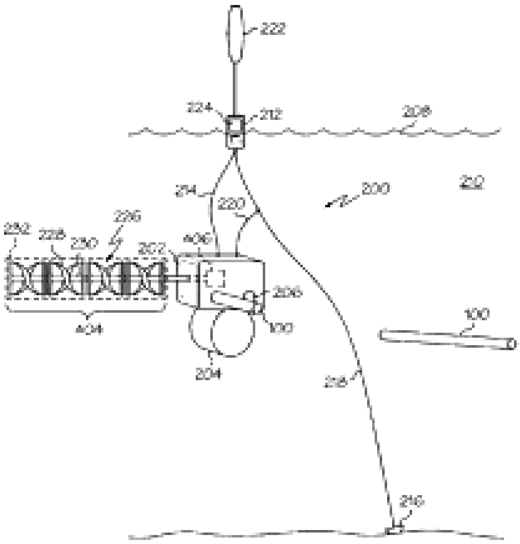
Hydro-Electric Farms
US Patent: 7,042,114 B2, May 9, 2006
Inventor: John E. Tharp, FL, USA



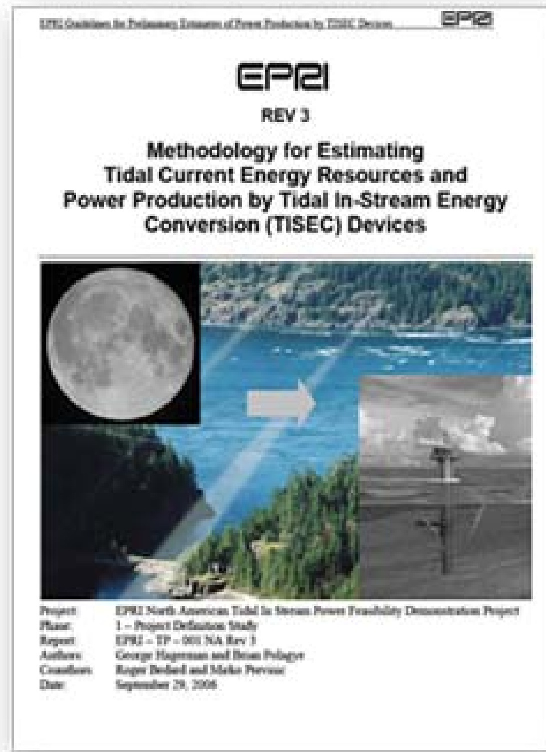
Submerged Run of River Turbine
US Patent Ap: US 2006/0127210 A1
June 15, 2006
Inventor: Ernst Buttler, DE, USA



Method and apparatus for retrieving energy from a flowing stream of water
US 2006/0019553 A1 June 20, 2006
Inventor: Joseph Voves, Chappaqua, NY (US)



Unmanned underwater vehicle turbine powered charging system and method
July 18, 2006
Wingett & Potter, USA

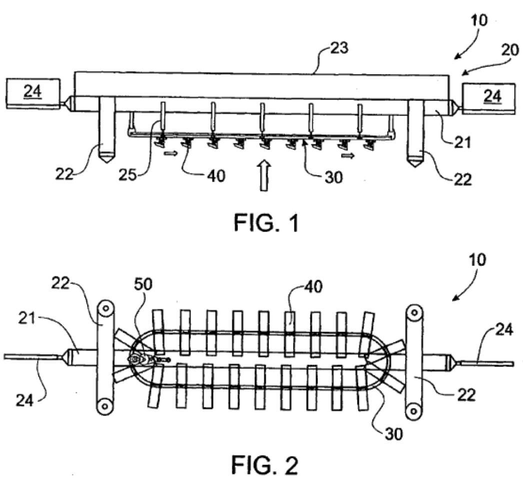


EPRI

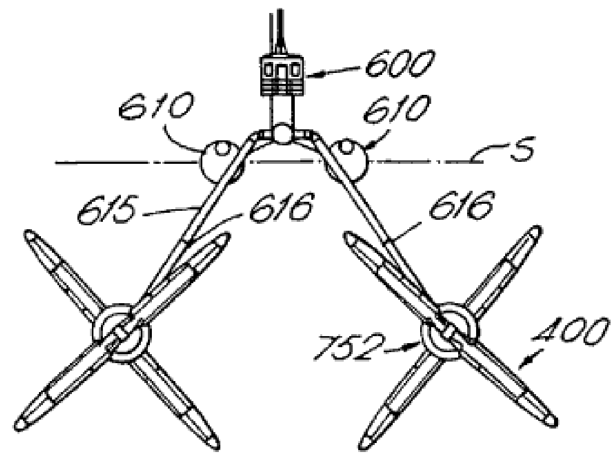
REV 3

Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices

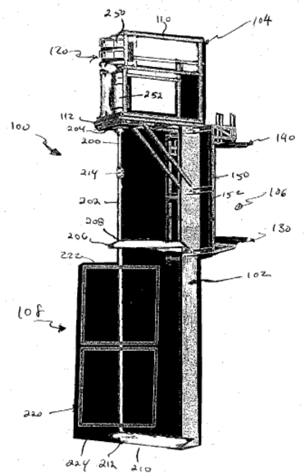
Project: EPRI North American Tidal In Stream Power Feasibility Demonstration Project
Phase: 1 – Project Definition Study
Report: EPRI – TP – 001 NA Rev 3
Authors: George Hagerman and Brian Polagye
Coauthors: Roger Bedard and Mirko Previsic
Date: September 29, 2006



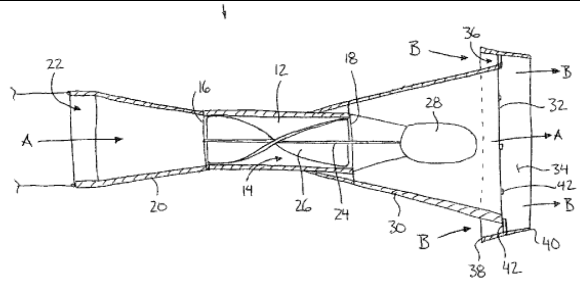
System of Underwater Power Generation
US Patent: US 2006/0192389, Aug. 2006
Assignee: Atlantis Resources Corp. Singapore



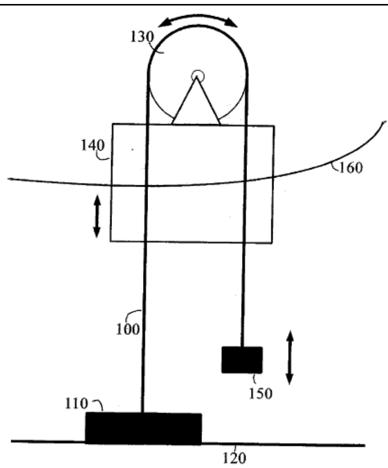
Plant, Generator and Propeller Element for Generating Energy From Water Currents
US Patent: 7,105,942 B2, Sept. 2006
Assignee: Hydra Tidal Energy, Norway



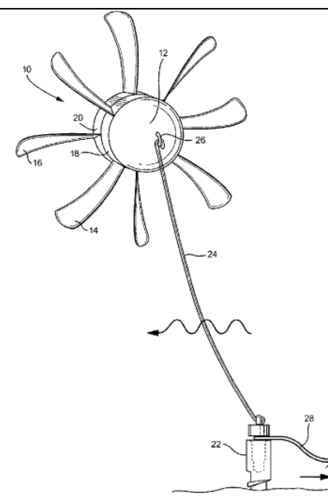
Single Sided Power Generator
Support Frame
US Patent Ap.US2006/0251510 A1,
Nov. 2006
Assignee: Verdant Power, VA, USA



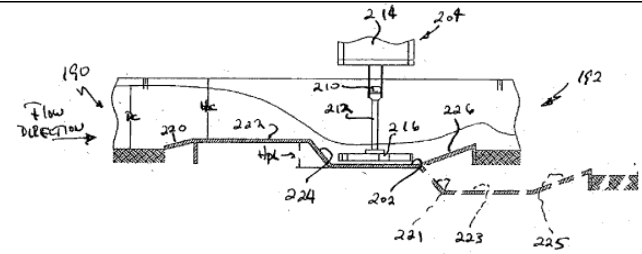
Hydro Turbine
US Patent: 7,147,428 B2, Dec. 12, 2006
Inventor: John Lamont, Winnipeg, Canada



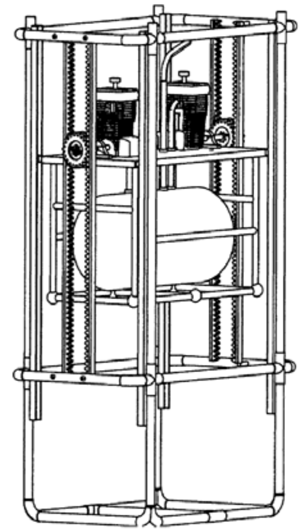
Method & Apparatus for Wave Energy Conversion - floating pulley & Counterweight
US Patent Ap: US2007/0018458, Jan. 25, 2007
Inventor: Melaquinas Martinez, MA, USA



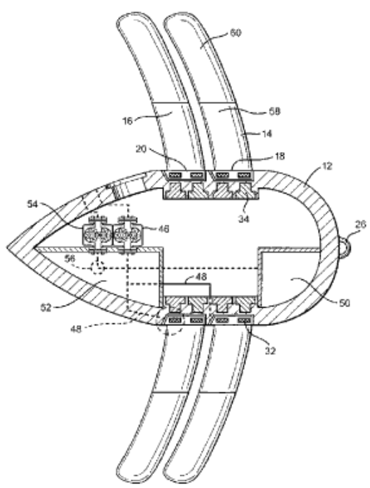
Water Current Generator
US Patent Ap: US2007/0007772 A1, Jan. 2007
Inventor: David Brashears, FL, USA



Kinetic Hydropower Generation from Slow Moving Water Flows
US Patent Ap. US2007/0063520 A1, Mar. 2007
Inventor: Jameel Ahmad
Assignee: Verdant Power

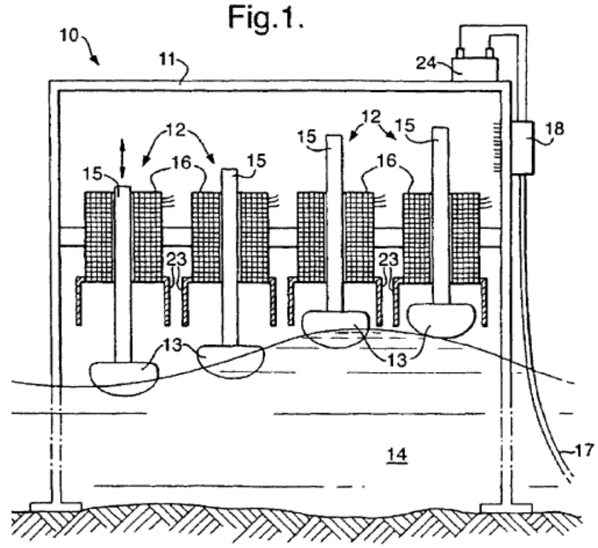


Integrated Ocean Wave Harness Unit
US Patent: US 2007/0089682 A1, Apr. 2007
Inventor: Reynaldo Mariansky CA, USA

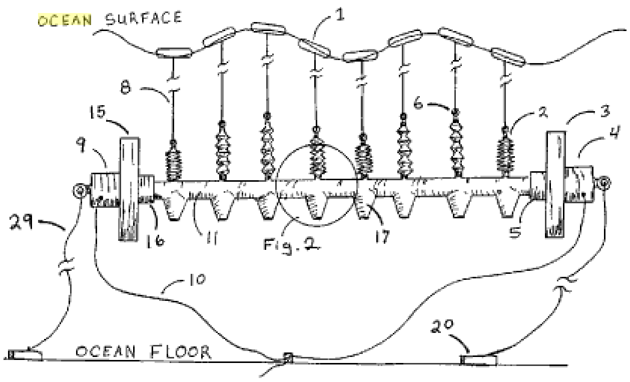


Water Current Generator
US Patent: 7,199,484, April 3, 2007
Assignee: Gencor Industries, FL, USA

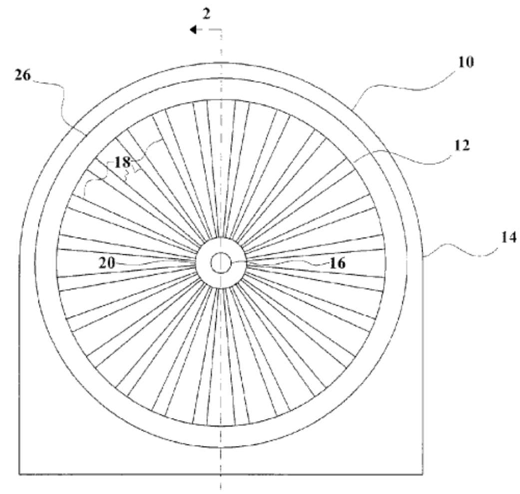
Fig.1.



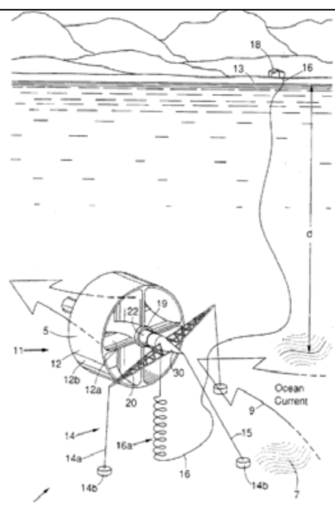
Method of Operation for a Self Protecting Wave Energy Conversion Plant
US Patent: 7,242,106 B2, Jul. 10, 2007
Inventor: Hugh-Peter Kelly, Essex, GB, UK



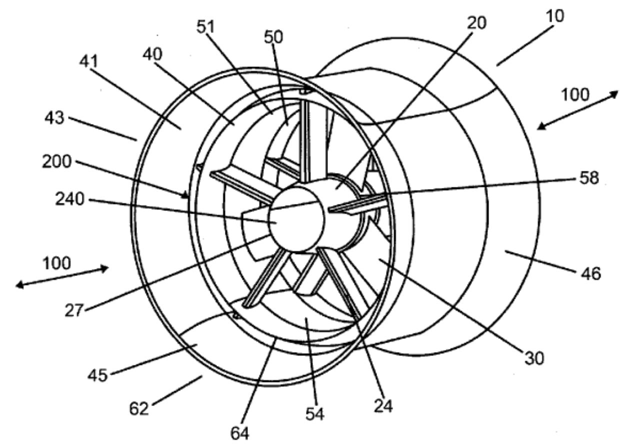
Ocean Wave Energy Converter
US Patent: 7,245,041 B1, July, 17, 2007
Inventor: Chris Olson, TX, USA



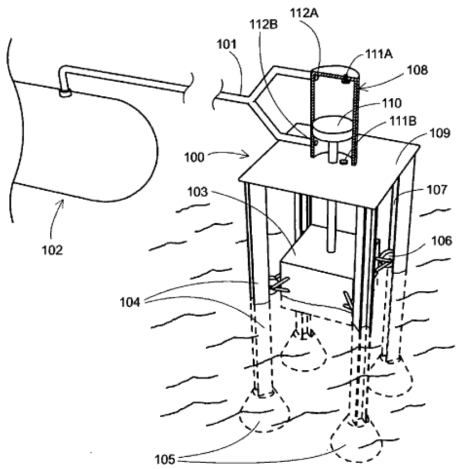
Ocean Current Power Generator
US Patent: 7,279,803 B1, Oct. 9, 2007
Inventor: Kenneth R. Bosley, FL, USA



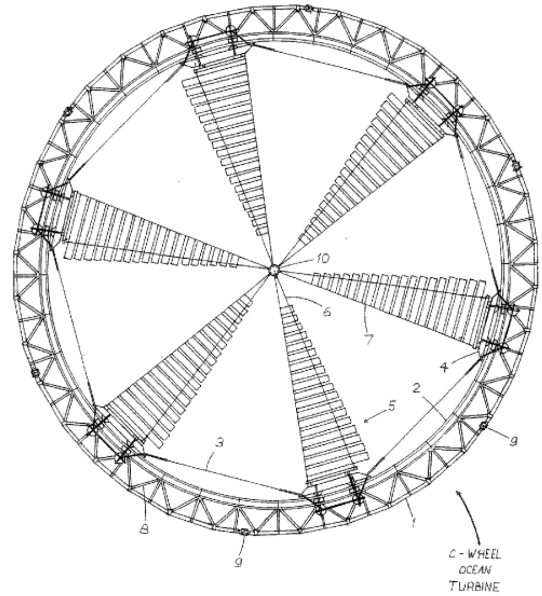
Submersible Turbine Apparatus
US Patent Ap. US 2007/0241566 A1,
Oct. 2007
Inventor: Manfred Kueule, MA, US



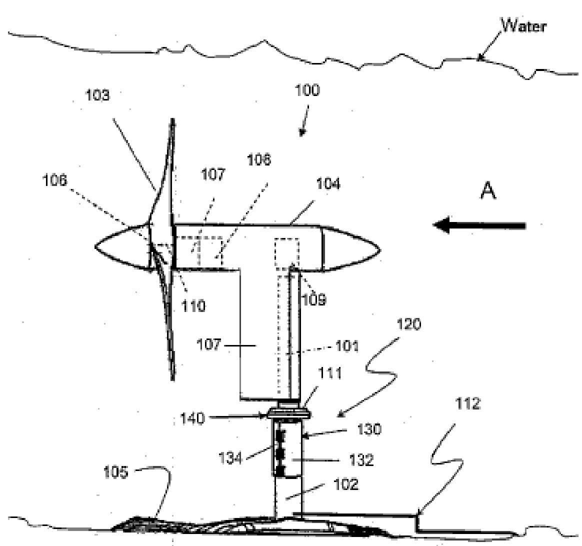
Flow Enhancement for Underwater Turbine
US Patent Ap.: US 2007 / 0284884 A1
Dec. 13, 2007
Inventors: Russel Stothers, Emmanuel Grillos
Miller Nash, LLP, WA, USA



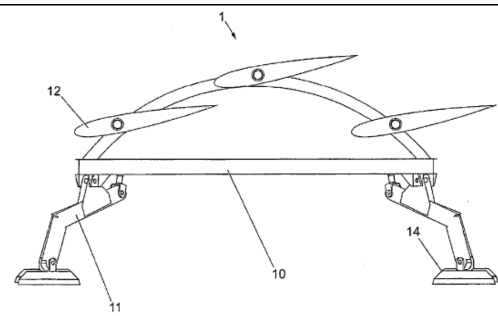
Wave Power Generator
US Patent Ap. US2007/0130929A1
Inventors: Ghazi Khan, Shabnaz Khan
Lincoln, CA, USA



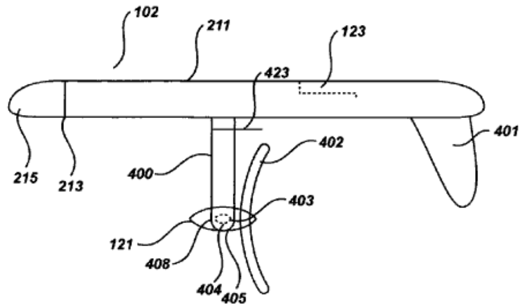
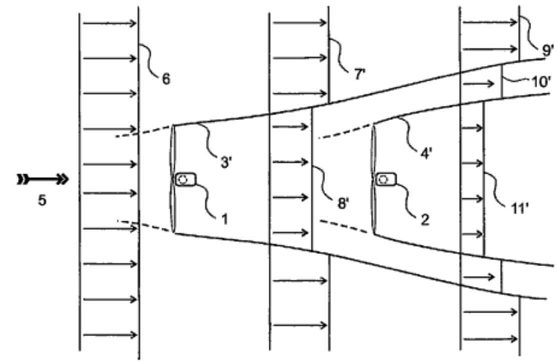
Carriage Wheel Ocean Turbine
US Patent: US 2008/0042444 A1, Feb. 2008
Inventor: Timothy Johnson, FL USA



Rotating Wedge Leveler
US Patent Ap. US2008/0056906 A1
Mar. 6, 2008
Assignee: Verdant Power



Apparatus for Controlling Underwater Based Equipment
(Launch, Position, & Recovery of Underwater Turbines)
US Patent: US 2008/0053358, Mar. 6, 2008
Inventors: Owen & Bryden, Aberdeen, UK

 River and Tidal Power Harvester US Patent Ap, US 2008/0093859, Apr. 2008 Inventor: C. S. Catlin, CA, USA	 Method & Installation for Extracting Energy from Flowing Fluid US Patent: 7,357,622 B2, April 15, 2008 Assignee: Stichting Energieonderzock Centrum, Netherlands