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Sea Energy — GEMA Catalog 2018

Carranza Hugo, Haim Alejandro, Pelissero Mario, Jorge Carlos Pozzo, Gallo Federico, Bagnasco Sebastian, and Tula Roberto

Academia del Mar, GEMA, Universidad Tecnológica Nacional F.R.B.A., Argentina

Abstract: It is in England and around the year 1750 that the beginning of the industrial revolution can be identified. From then, the industrialization and the increasing consumption of energy are inevitably associated. Then and until now, the demand for fossil fuels and the industrial growth are fully extended. First it was the mineral coal (which continues), then the oil and later the gas provides that energy. Note that the three sources are non-renewable and they are widely used in thermal machines, either external combustion (boilers), or internal combustion (cycle Otto-Beau Rochás, Diesel, Bryton); all of them produce gases and polluting particles. For a better understanding, the requirements of societies can be compared in three historical periods, separated one hundred years from another. In the beginnings of industrialization coal predominates (until the last third of the 19th century); then oil and some water sources continue and in the current stage (since the mid-twentieth century) coexist with nuclear energy (which began commercially in 1957. USA) the renewable energy, from the wind, the sun, the biomass, the thermal of geological origin and also in a slow way we began to use the sea energies.

Key words: industrial development, fossil fuels, renewable energies, marine energies, environment

1. Introduction

In order to compile a the most successfully devices to obtain energy from the ocean around the world, the GEMA group (Sea Energy Group) — a branch of the Sea Academic of Argentina — and the Wave Energy Research Group of the National Technological University of Buenos Aires (UTN.BA) were working together to publish this catalog.

By the end of 2014, the first edition of the catalog was presented, in that case we compile and catalog all the devices that harvest energy from the sea (including rivers), with the only condition of having been built and worked in the water or experimental channels, regardless of whether or not they continue working nowadays. In December 2018, at the headquarters of the Naval Hydrography Service (SHN) of Argentina, we presented a new edition, *ENERGÍAS DEL MAR — Catalog 2018*, 2nd edition. Both have been published on free access websites, with the aim of spreading this knowledge and promoting research interest on the subject.

2. Importance of Energy

Nations have vital interests; they are issues of such importance that affect seriously their development. These objectives change according to historical moments; for example, some European countries between the seventeenth and eighteenth centuries begun the accumulation of precious metals such as gold and silver; in the seventeenth to the nineteenth centuries the dominion of the seas was the goal; the United Kingdom of Great Britain, France, Holland, Portugal and Spain were the most relevant examples. During the nineteenth century the expansion of borders was considered crucial and a constant affaire, especially in the nations of the America, USA to the west, Argentina to the south (Patagonia), Brazil to the west (Amazon). But United Kingdom, France, including USA, etc. and other countries anticipates the

Corresponding author: Jorge Carlos Pozzo, Msc Engineer; research areas/interests: sea energy. E-mail: jorge.pozzo@set.ypf.com.

growing industrialism and the vital issue was to capture the energy sources. The following tables indicate how the energy requirements of humanity evolved in the last two centuries (Fig. 1).

1919			
Fossils Non-renewable			Hydraulic Partially renewab
Fuel Oil	Petroleum	Mineralogy Coal	River water
Steam engines	Steam engines	Steam engines	Dam turbines
Turbines	Turbines	Turbines	Pelton Turbine
Diesel Engines		Reciprocating engines	

1819	
Fossils	Trees
Non-renewable	
Mineralogy Coal	Charcoal

2019							
Fossils Non-renewable			Nuclear Singular case [1]	Hydraulic Partially renew [2]	Wind Renewable [3]	Solar Energy Renewable	Ocean Renewable
Gas	Diesel oil	Mineralogy Coal	U_{235}	River water	Wind	Sun	Tidal energy; dam, bubble Kaplan turbine
Steam engines	Steam engines	Steam engines	Steam engines	Kaplan (axial turbine)	Rotary, low revolutions, multipolar	Photovoltaic panels, others	Ocean wave energy
Turbines	Turbines			Francis (radial turbine)			Marine currents
Piston reciprocating engines	Diesel engines			Pelton (high speed turbine)			Ocean thermal converter
Stirling engine	Stirling engine			Others: small rivers, narrows channels			Saline differential (Ibas prototypes)

Fig. 1 Matrix of energy requirements.

Already established the vital issue of access to energy, we consider the countries as unique, ideal and monolithic entities, without thinking about value judgments, we will show some historical examples of different kind of situations:

- The occupation of the Rühr coal mines by France from 1923 to 1925;

- The urgency of Germany Government for the uranium mines of Czechoslovakia (1939);

- The strangulation of the oil supply to Japan prior to the attack on Pearl Harbor (1941);

- The assurance of the USA Government for the provision of high quality uranium mineral from the Katanga mines, Congo (1942);

- The Germany Government need for oil from Romania and the Caucasus during WWII and change his war strategy.

Note 1: Nuclear energy (1) is a strictly non-renewable resource, but due of its performance we classify it as a singular case. The hydraulic (2) is a renewable energy, but the climatic effects known as El Niño and its counterpart La Niña and others situations associated with global warming (for example, unexpected droughts) make it not an absolutely regular resource. The wind (3) can be statistically predictable in certain regions (for example in Patagonia) but it may happen that there are moments of complete calm.

Closing this paragraph on the meaning of vital interests for nations and for a better understanding of the subject, we quoted textual to the preface of the document “National Interest: from abstraction to strategy” by M. Roskin Chapter 6. He says 'We have no eternal allies and we have no perpetual enemies. Our interests are eternal and perpetual, and those interests are our duty to follow” [1].

3. Methodology

We have typified the technological landscape in the State of Art [2], which has meant tracking, classifying and cataloging what has been published worldwide in terms of advances in the use of sea energy. The “State of the Art” has as meaning to track all the information about developments related to a topic; we will follow the three-step methodology proposed by Molina Montoya [3]: (1) Contextualize: means to define the studys topic, the limits of the study and the main source of data collection and contextualize means determine a set of circumstances that occur around a fact and end up giving it meaning. (2) Sort: determine the way of dealing with information, which can be according to chronology or by types of machinery; for our case a class is a set of things with common characteristics. (3) Categorization: is related to the organization and classification by some kind of order and hierarchies.

The systems for capturing energy are classified into 5 large groups: saline gradient, thermal gradient, waves, currents and tides. The first system from the salt gradient is still in the research stage; there are some commercial equipment related to tides, thermal gradient, wave and marine currents; and also a lot of them are in experimental stage. For example, the first thermal gradient energy installation has been working since September 2015. However, we will not ignore the advances in the devices based on the saline gradient; some projects are on theoretical development; we expect that this technology brings a new possibility for energy harvesting from the sea; on the other hand wave energy plants are the ones with the greatest constructive diversity, since they can take advantage of the potential and kinetic energy, or both at the same time. More simple are the use of marine currents caused by the tides or the natural displacement of the sea water; the generation of electrical energy is made from the transformation of the kinetic energy of the sea in a rotating movement, this is the best situation to use synchronous electric three-phase generators.

However, we must make explicit our limits of this presentation: since the subject of study of the GEMA in general terms is to get of energy through alternative renewable resources, this catalog focuses on energies very low environmental impact but our especiality are marine devices and this agrees with the philosophy that we want to show from GEMA Group. On the other hand, even if marine devices are in accordance with wind generators, photovoltaic solar panels, water other fluids heating tubes or solar photovoltaic power plants by concentration of solar radiation, they are not despicted in our catalogue. And more, most of these devices are commercially working as a mature technology for several decades and are widely spread all around the entire world. This does not happen with the devices that harvest the energy from the sea; only a few of them have the technological and commercial maturity to be used, but sea energy offers an interesting opportunity to explore the possibilities to harvest it in a practical way; exploring the international situation is an excellent exercise to reference our own project related with marine energy. In fact, UTN.BA is development a WEC generator. Finally as a benefit not enough mentioned on renewable energies, is the fact of the sovereignty that nations have to take advantage of their entirely free natural resources such as sun, wind, marine energy, biomass, geothermal, etc., for the welfare and development of their people.

4. Catalog Structure

But what is a Catalog? From the etymology, is a composite word. It comes from the Latin catalŏgus and this from the Greek κατάλογος (catalogs). The prefix κατά means "down/in/on/towards", while the verb λέγειν (léguein) is "collect", "put together". Therefore καταλέγειν means "order according to a principle or system". The definition according to the Cambridge Dictionary: "a book with a list of all the goods that you buy from a shop"; "A list of all sort of objects like books or paintings that exist in a place" [4]. Definition according to the Spanish Royal Academy Dictionary: "(1) tr. Register in a catalog books, documents, species or other elements. (2) tr. Classify someone or something in a class or group" [5]; in Spanish, the word was documented for the first time in 1353. We conclude by saying that, for our work, a Catalog is an orderly relationship in which we include or individually describe objects, mechanisms, books, documents, and people that are related to each other.

Having said this, and following the guidelines explained in the previous paragraph 3 (Methodology), of our catalog, we have privileged the information of the equipments that are all ready built or in the mode of testing, whether they are nowadays working or not and that the mechanisms or facilities are related to the electrical energy production. The Classification will be ordered in five classes: tidal, waves, hydrokinetic (marine, tidal and fluvial), thermal marine and saline gradient. Finally, the Categorization, where in the first term are shown the systems with the highest degree of development and within them begins with the oldest.

5. Brief Exposure of This Catalog: Examples

According to the classifications and categorization criteria, we will show some examples of our work like figures, photographs and geographical locations, brief explanations of the technical characteristics and other data. Therefore, this is a summary of our work "*Energías del Mar-Catalog 2018*", 2nd edition.

5.1 Tidal Energy

To illustrate on the subject, we will show two great examples. The first one is the La Rance tidal power station in France (1967) and the second case is the Sihwa Lake tidal power station in South Korea (2011).

5.1.1 La Rance Tidal Power Station: France

When this power station begin to work the world astonishment awoke, because for the first time a country had managed to harvest massive energy from the sea, using the difference in height of the tides; the difference between the high and low tide is only 8 meters. There are other places in the world where this difference is much more. But they were the pioneers for almost half a century. The station begins to work on November 26, 1966 inaugurated by the President Charles de Gaulle [6] (national hero of France, he led the liberation of France in WWII). The construction began in 1960; the dam is 330 m long and on the top there is a route for vehicular circulation of two lanes in each direction. It forms a lake of 22 km^2. The machinery consists in 24 axial flow bulb turbines, of 5.4 meter diameter and can generate 10 MW each one, the total generating capacity is 240 MW, the turbines are bidirectional, they can work at low and the high tide.

5.1.2 Sihwa Lake Tidal Power Station: South Korea

Almost half a century later the La Rance power station could be overcomed; that was when the Sihwa Lake power station began to work. The construction began in 2004 and in 2011was ready. The Sihwa Lake station has a total power of 254 MW.

The Rance power station reaches its 240 MW power with 24 bulb turbines, while Sihwa has only 10 turbines but 25.4 MW each one. However, Sihwa only operates

Fig. 2 La Rance.

Fig. 3 Sihwa

with incoming tide, it is not bidirectional, it works half time. But we can be seen that there was a remarkable technological advance in terms of the individual energy capacity of each turbine [7].

5.2 Wave Energy

These devices are called Wave Energy Converters (WEC). In general generators are simply energy converters. For example, a generator with Otto-Beau de Rochas cycle uses gasoline and delivers mechanical movement, an electric motor take in electrical current and delivers mechanical movement, an electric generator gets mechanical movement and delivers electricity. The conversion of the oscillating movement of the waves into electricity is feasible and is the one that presents the greatest number of devices; we will show just a few.

5.2.1 UTN.BA Prototipe, Wave Energy Converter: Argentina

This began as a research project at the National Technological University of Buenos Aires. It was built a 1:20 scale model to ensure the feasibility of the project. Then, a functional prototype was built at a scale of 1:10, this device was installed and tested in a wave generation channel. Its operation was successful moving a 50 W generator. The image shows the testing process at wave channel of the National Institute of Water (INA, Ezeiza, Argentina) [8].

Then, a conceptual exercise was carried out that allowed to analyze its behaviour at the sea in a real

Fig. 4 UTN.BA.

scale prototype, making use of differential equations of second order, linear, ordinary, constant coefficients [9]. Currently, from an agreement with a private company, the construction of a full scale device is being carried out. We hope to put it in function at the breakwater of the Mar del Plata port, Argentina.

5.2.2 Mutriku, Wave Energy Converter: Spain

The Mutriku power station is working for almost 6 year; is located in the coast city of Mutriku in the Basque Region of Spain [10]. The device was built under the concept of Oscillating Water Column (OWC).

Fig. 6 illustrates its operation.

Fig. 5 Mutriku.

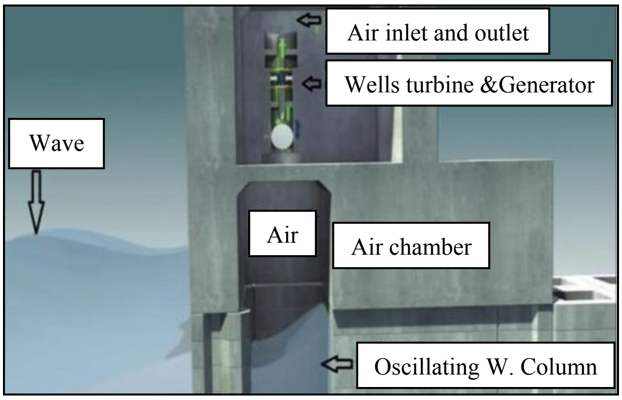


Fig. 6 Conceptual Mutriku.

The wave pushes the column of water and the water in the hole pushes air inside the chamber. Then the air begin to move the Wells turbine [11]; the Wells turbine moves always in the same direction even though the air current is going up or down the chamber.

5.3 Hydrokinetic Systems

The sea is an extraordinary source of marine currents capable of being used; same situation happens with rivers, streams and channels. In the oceans there are a lot of places where there are strong currents, both on the surface and below them. The currents that are below the surface are away from the climatic perturbations of the surface; this is an advantage to harvest energy because the current have always the same direction and power. The equipment used is similar to wind turbines, but its advantage is that they don't have to rotate on the azimuthal plane to face the current. Since the speed of the current are almost constant, they can deliver energy continuously all the time. Some turbines may be submerged in places with tidal current; in this situation there is no need to have a dam to contain the water.

5.3.1 Seagen, Hydrokinetic Systems, Northern Ireland

This device located in Strangford Narrows in Northern Ireland (NI) started as the Seaflow Project with only one generator. When it was verified the feasibility of the project, it evolved into the current Seagen device, equipped with two twin generators that delivers energy to the commercial electricity network.

Maintenance task is carried out by raising both generators. The axial flow rotors are 16 m in diameter, with blade angle attack control. The assembly is mounted on a single column, a steel pillar of 2.1 m diameter.

The 2008 device weighs 1000 ton and each generator delivers 600 MW [12, 13].

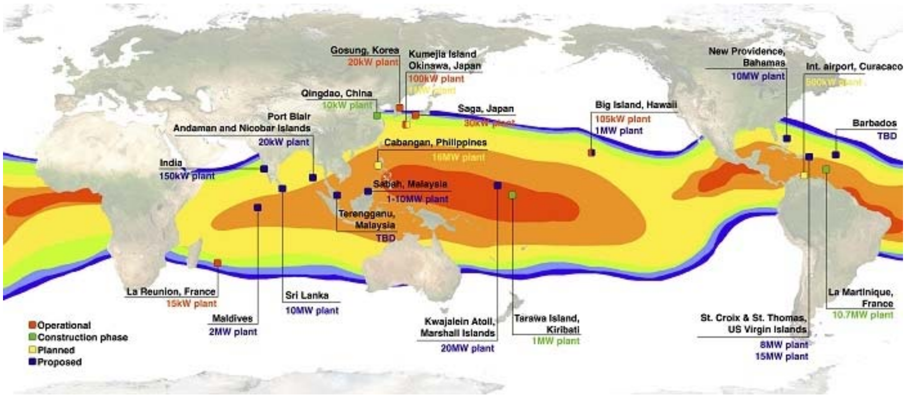
5.3.2 Kobold Turbine, Hydrokinetic Systems, Italy

Kobold is a cross flow turbine. It can work with speed currents of the order of 1.5 m/s.

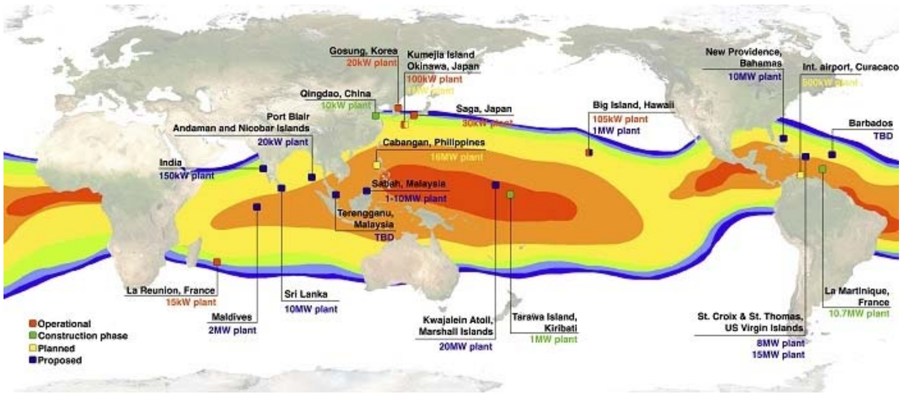
Fig. 7 Seagen, render.

Fig. 8 Seagen real.

Fig. 9 Turbine at the time of lifting.



Status of Otec Power Plants (May 2017)



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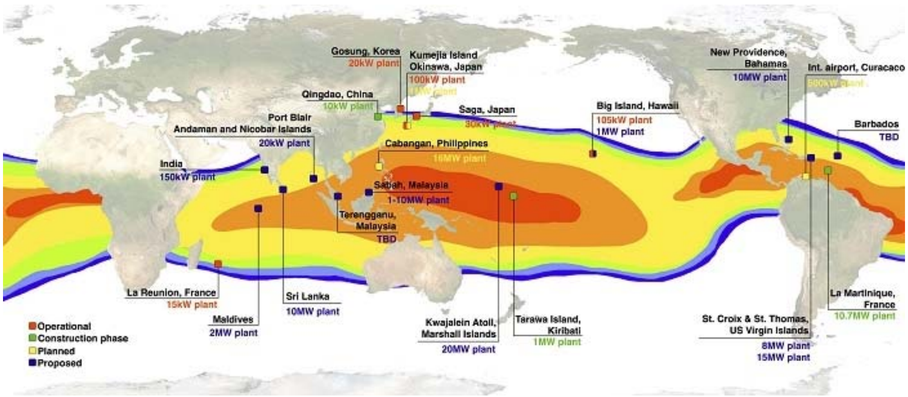

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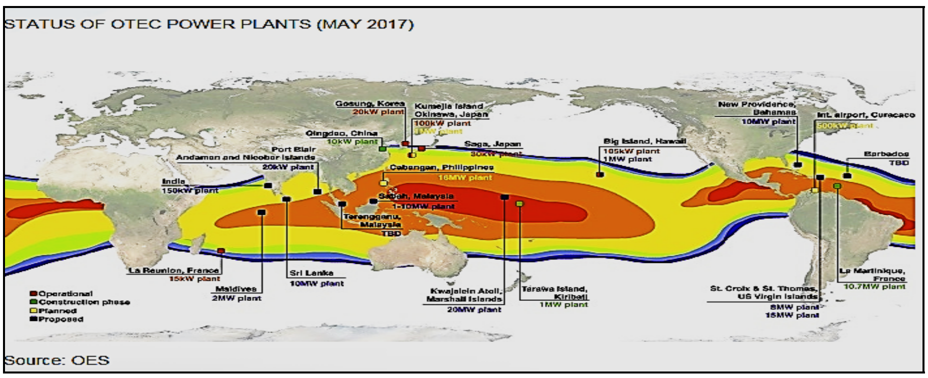

Fig. 10 Thermal differential plants in the world [15].

From the numerical modeling, a maximum efficiency of 42% was estimated for this turbine. A device of 130 kW was developed in 1981 by the Hydro Company and put it 20 m depth at the end of 1990 in the strait of Messina, Italy [14].

5.4 Ocean Thermal Energy Converter

This system is called Ocean Thermal Energy Converter (OTEC). The concept is simple and it´is need to an easily vaporable fluid. For example ammonia (NH_3) or Tetrafluoroethane (CH_2FCF_3). This device has a heat exchanger that vaporizes the fluid with seawater from the surface; the surface water temperature is around 25°C (77 F); the vaporized fluid is sent to a low pressure turbine and the turbine´s energy moves an electric generator; the steam is condensed with the sea water collected from 1,000 m depth at 5°C (41 F) temperature and the physical process begin again. This process is called “low enthalpy” because the thermal difference between high and low temperature is only 20°C (36 F). These environmental conditions are only in the equatorial region of our planet, between the Tropics of Cancer and Capricorn.

5.4.1 Makai Ocean Thermal Energy Converter

In August 20 of 2015, starts an OTEC power station; this station delivers 100 kW to the network in Hawaii. This facility was built and operated by Makai Ocean Engineering [16], currently the largest company in the world that operates OTEC. The technological innovation was based on the improvement of the heat exchangers that represent 1/3 of the cost of the plant,

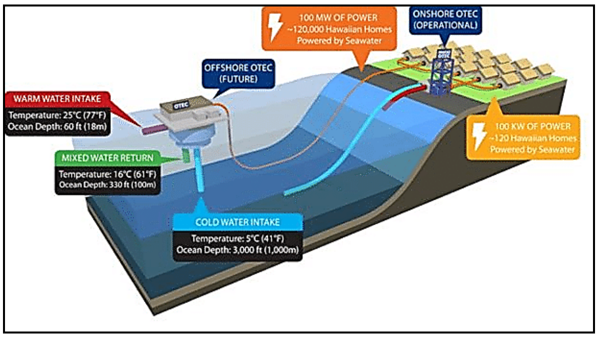

Fig. 11 Makai converter [17].

this improvement led to obtain the best performance with the lowest cost and also they are much more resistant to corrosion. The cost was around USD 5 million.

This converter provides electricity to 120 families on the island. In addition the electricity is generated in a station located on the island, however in the final project the electric generator will be located in a vesselship.

5.5 Saline Differential

The energy generation of this technology is based on the different salt concentration between sea water and river water. When a semipermeable membrane is placed between both solutions we can see that only the water of the river with low salt concentration moves through the membrane to dilute the sea water. This phenomenon is called “osmosis”; this situation results in two proposals for electricity generation; in one case, take advantage of the relative elevation of the level of sea water (salt water) over the water of the river (fresh water). This generates a pressure differential that produces a displacement of the solution to move an electrical turbine and another would be the ionic transfer between the solutions generating a direct current.

These two systems are still in experimental state in the laboratory.

The two most widespread systems are the following:

(1) Pressure Retarded Osmosis (PRO)

This method was developed by Sidney Loeb and it was patented in 1973 (Israel) and in 1975 (USA). It’s based on the osmosis phenomenon. In a reservoir that contains marine water, the system introduces low salt water through the semipermeable membrane and increases the volume of salt water, this procedure moves a hydraulic turbine coupled to an electric generator [18].

(2) Reversed Electro Dialysis (RED)

This system uses the ion exchange between drinking water (low contein of salt) and sea water. In this device

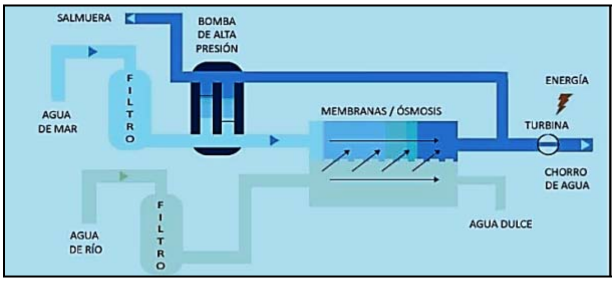

Fig. 12 PRO plant.

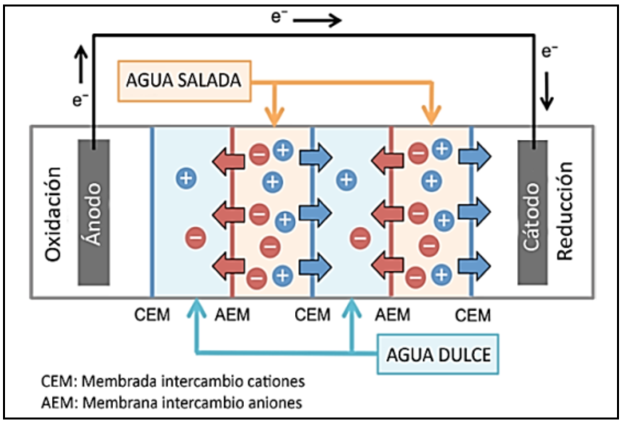

Fig. 13 Planta RED.

the solutions are separated with membranes that allow the migration of the ions. Both the anions and the cations move through selective membranes where electricity is generated in the form of direct current. It is the only one that has no moving parts and directly generates direct current [19].

6. Conclusions

The comparison between the first and second edition of the catalog will be made in the following table (Fig. 14). In both editions, a meticulous search has been made of diverse equipment and devices, capable of capture the energy of the sea, including the devices we find in rivers and channels. The growth of information in the 2nd edition is attributed to a more careful search and also to the fact that in the four years between 2014 and 2018, the numbers of prototypes were twice. This is extremely encouraging, because it shows a trend with a steady growth of interest in this type of renewable, environmentally friendly energy in addition to the widespread understanding that the replacement of fossil energy sources present us with other friendlier alternatives that we trust to take hold at the second half of this century.

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