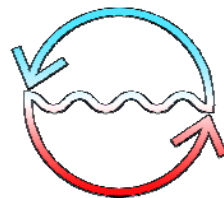


OCEAN THERMAL ENERGY CONVERSION (OTEC)

Commercial Implementation and its Implications

Presentation to:

**Institute of Electrical Engineers
College of Professional Engineers and Surveyors
of Puerto Rico**



**Offshore Infrastructure Associates, Inc.
August 8, 2008**



OTEC:

Basic Concepts, History and Future

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August 8, 2008

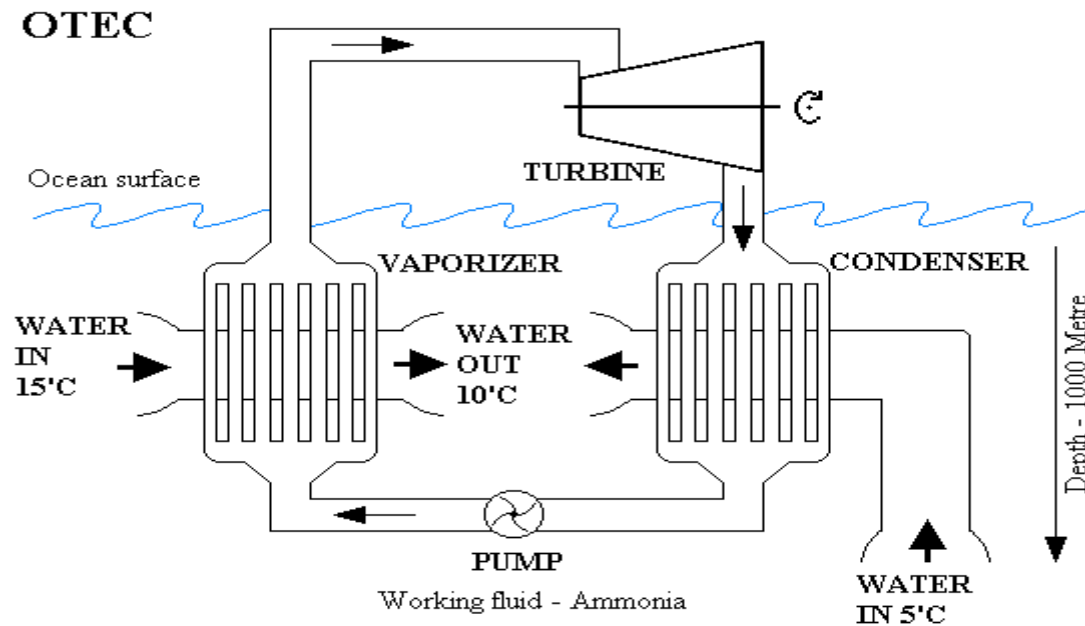


What is OTEC?

- Offshore Thermal Energy Conversion (OTEC) uses the heat energy stored in the Earth's oceans to generate electricity.
- Works in areas where the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about 20°C (36°F), in an environment that is stable enough for efficient system operation. In effect, it works by recovering some of the solar energy received by the oceans
- Principally applies to tropical areas with deep ocean waters
- OTEC allows production of electricity (and desalinated water) from purely local sources at a fixed cost.
- Minimal environmental impacts as compared to other sources



Schematic Description of OTEC



Difference in temperature between deep, cold water and hot surface water is used to vaporize a working fluid, which runs a turbine and generates electricity.



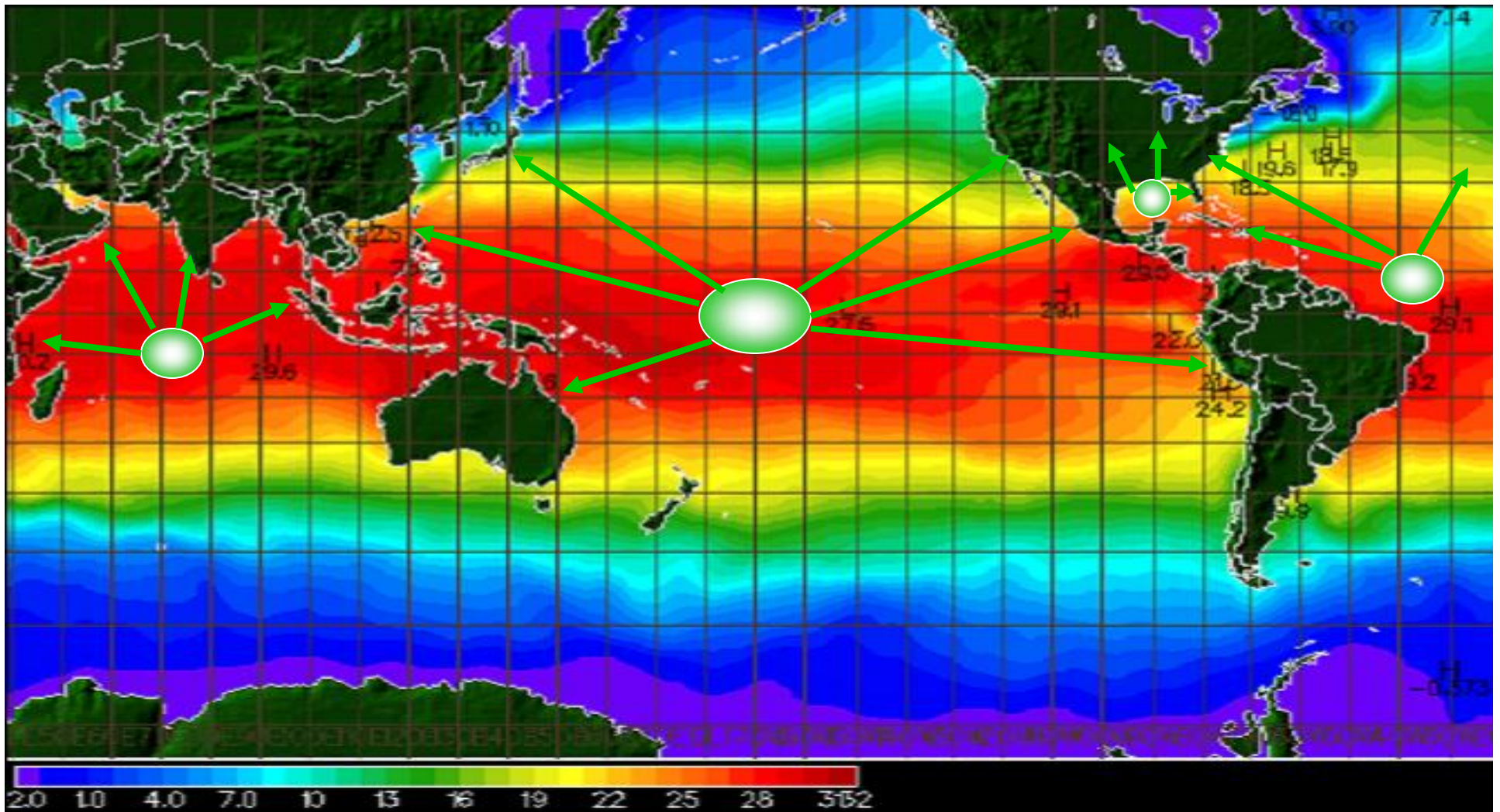
OTEC Characteristics

- No fuel needed.
- Cost is essentially capital cost of plant, plus O&M. Fixed from Day 1, **no volatility**.
- Energy from **local sources at fixed cost**. Not vulnerable to external factors
- Environmentally benign.
- **Can concurrently produce potable water**
- Very high availability factor (>85%)
- **Cost is known and fixed from day 1**. No volatility
- Public tends to be receptive to idea, once the basic principle is understood.



Where will OTEC work?

Tropical regions all over the globe



Best Location for OTEC in the World

North →

SE Puerto Rico
is ideal location

PUERTO RICO

- Deep water very close to shore
- Large power consumption
- Industrial society
- Extremely high educational level
- Stable politically and economically
- Very favorable tax laws

Can serve as base to provide OTEC services to other locations.



History

- Idea conceived by Jules Verne in *20,000 Leagues Under the Sea*, published in 1869.
- Jacques D'Arsonval formally proposed the idea in France in the 1880's.
- His disciple, engineer/entrepreneur Dr. Georges Claude, who improved the air liquefaction process, and invented neon lighting, built an experimental plant in Ougree, Belgium, using a lake as cold water source and thermal effluents from a factory as hot water source. Temperature difference about the same as for OTEC.
- Based on good results of Belgian experiment, Claude builds the first OTEC plant in Matanzas, Cuba in 1930.
- Major problem: Climate. There are no tropical weather systems in France...



Claude's Work in Cuba and Brazil

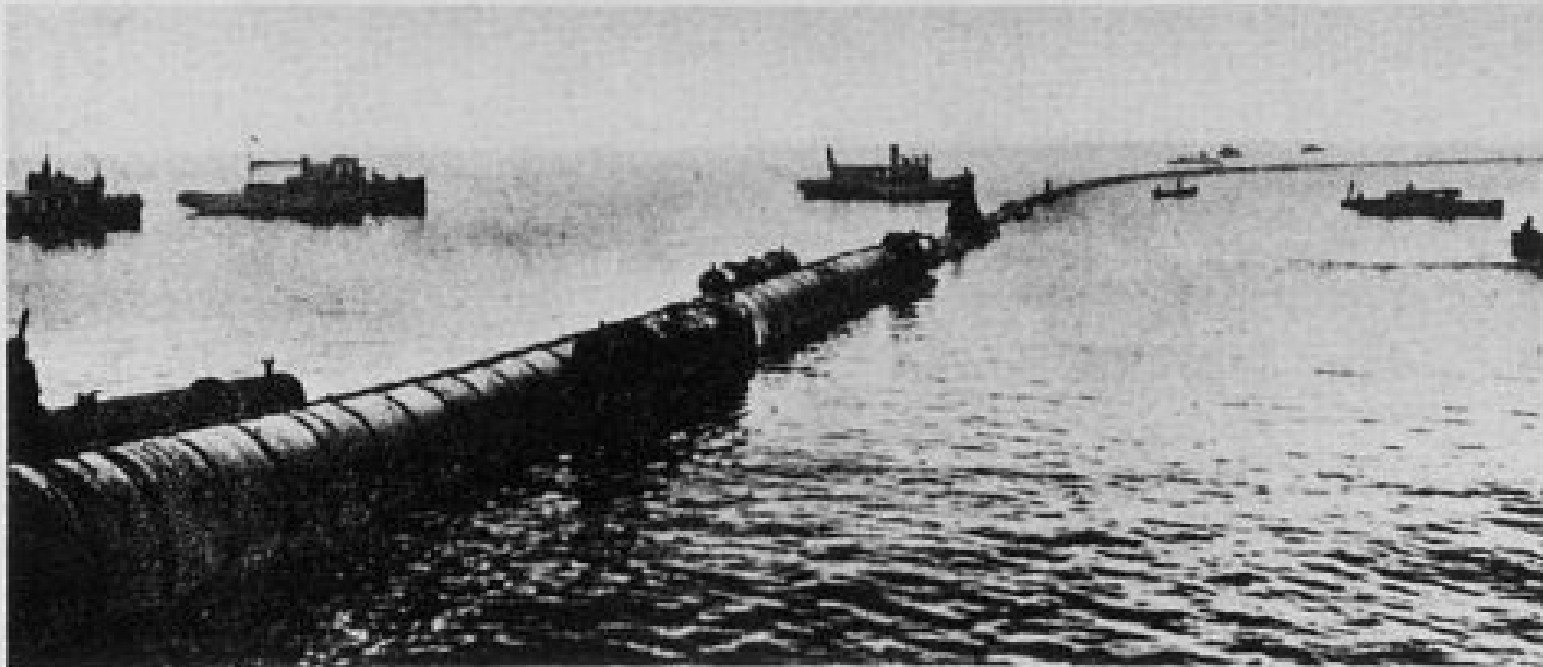
- Dr. Claude self-financed the venture.
- On October 6, 1930 Claude's team started a 22 kW generator and lit an array of lamps.
- Work was presented at Cuban Academy of Sciences shortly afterwards and later in international journals.
- Wanted to build larger plant in Cuba's South Coast.
- Plant operated only 11 days, destroyed by major storm
- After Cuban failure, he made a second attempt in 1935 at Brazil, aiming to produce ice. Also failed (CWP lost in storm).
- Claude suffered major financial losses.



Corrugated Steel Cold Water Pipe Used by Claude in Cuba, 1930

Source: *Club des Argonautes*

Energie thermique des mers



1930 : Expérience de mise à l'eau d'un tube de 1,60 m de diamètre et de 2 km de long, à Cuba (Georges Claude).

Installation of Cold Water Pipe in Matanzas, Cuba, 1930

Source: *Club des Argonautes*

MECHANICAL ENGINEERING

Volume 52

December, 1930

No. 12

Power From the Tropical Seas'

Process Utilizing Difference Between Temperatures of Water at the Surface and at the Lower Depths—Expedients Employed in Locating and Submerging a Line of 6-Ft. Pipe a Mile and a Quarter in Length—Results With Experimental Plant—The Inventor's Predictions for the Future

By GEORGES CLAUDE,* PARIS, FRANCE



SIX months ago The American Society of Mechanical Engineers conferred on me, as a representative of the engineering profession of France, its Fiftieth Anniversary Medal. Having only a few weeks since succeeded in solving a problem which has held and continues to hold the interest of the engineering world, I pray you to find in this account of my work the manifestation of my deep gratitude for the honor done me and for the particular welcome which your great

country has always extended to my inventions.

First of all, let me explain exactly what we have been trying to do. We have not been endeavoring to extract power from the waves, from the tide, from streams. What we had in mind, my friend Boucherot and myself, was to utilize the remarkable

and friend D'Arsonval as far back as 1882, followed by the American engineer Campbell, and the Italian engineers Dornig and Boggia. It is fortunate that I was not aware of this at the time I became interested, for, as you know, a beaten track has little allure for a good inventor, and quite probably we should have abandoned the trail before discovering what interesting things it finally led to.

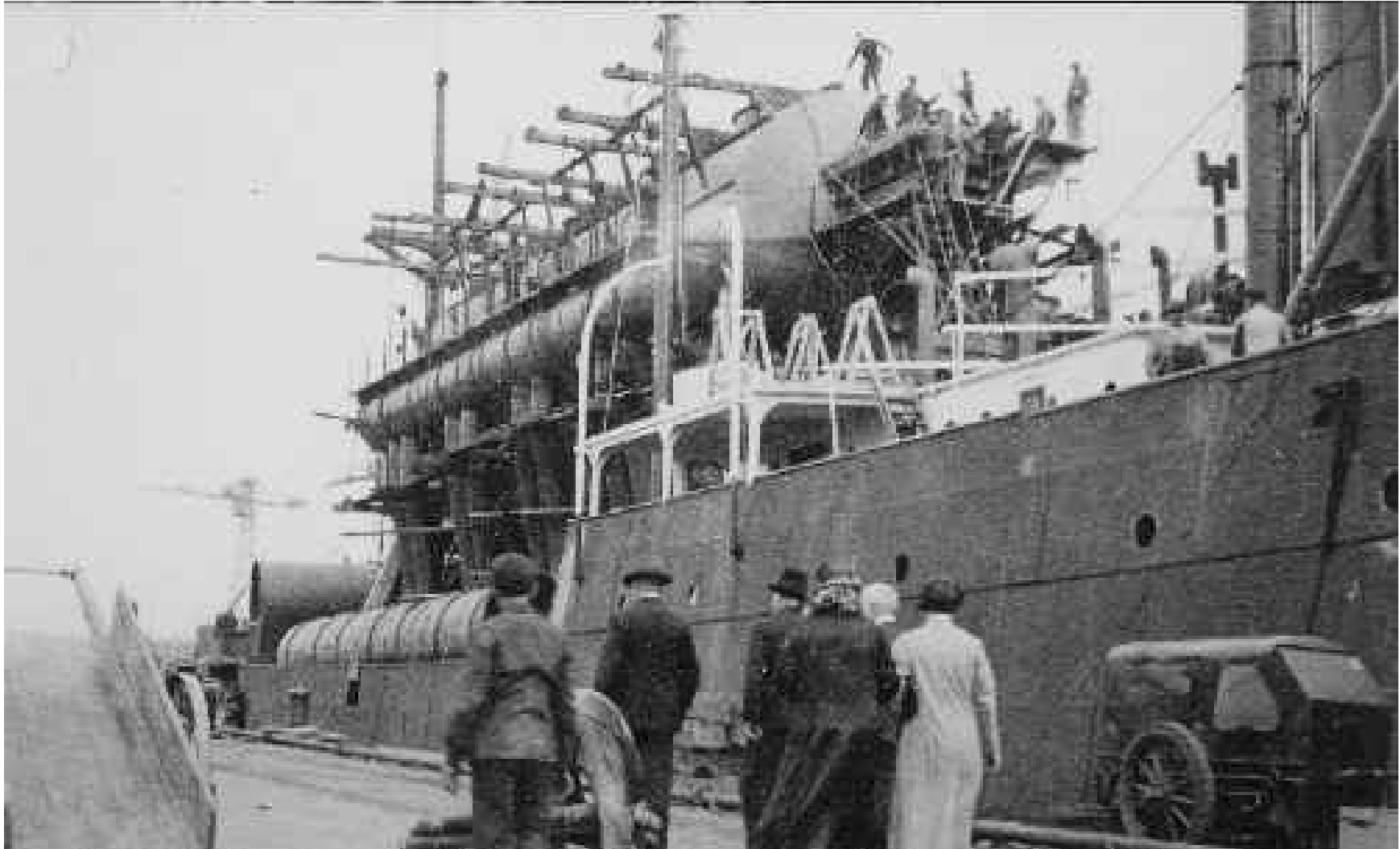
While theory indicates that by utilizing our difference of temperatures it is possible to get power, it leaves us the choice of means. The inventors referred to proposed a means, namely the use of liquefied gases, vaporized under pressure by the tepid surface water, and then condensed by the cold water after their expansion in a motor. Manifestly such a solution is burdened by a number of inconveniences, one of them being the high cost of such evanescent substances, and another the necessity of transmitting enormous quantities of heat through the inevitably dirty walls of immense boilers with such a small difference

Claude reports on Cuban OTEC experiment, 1930



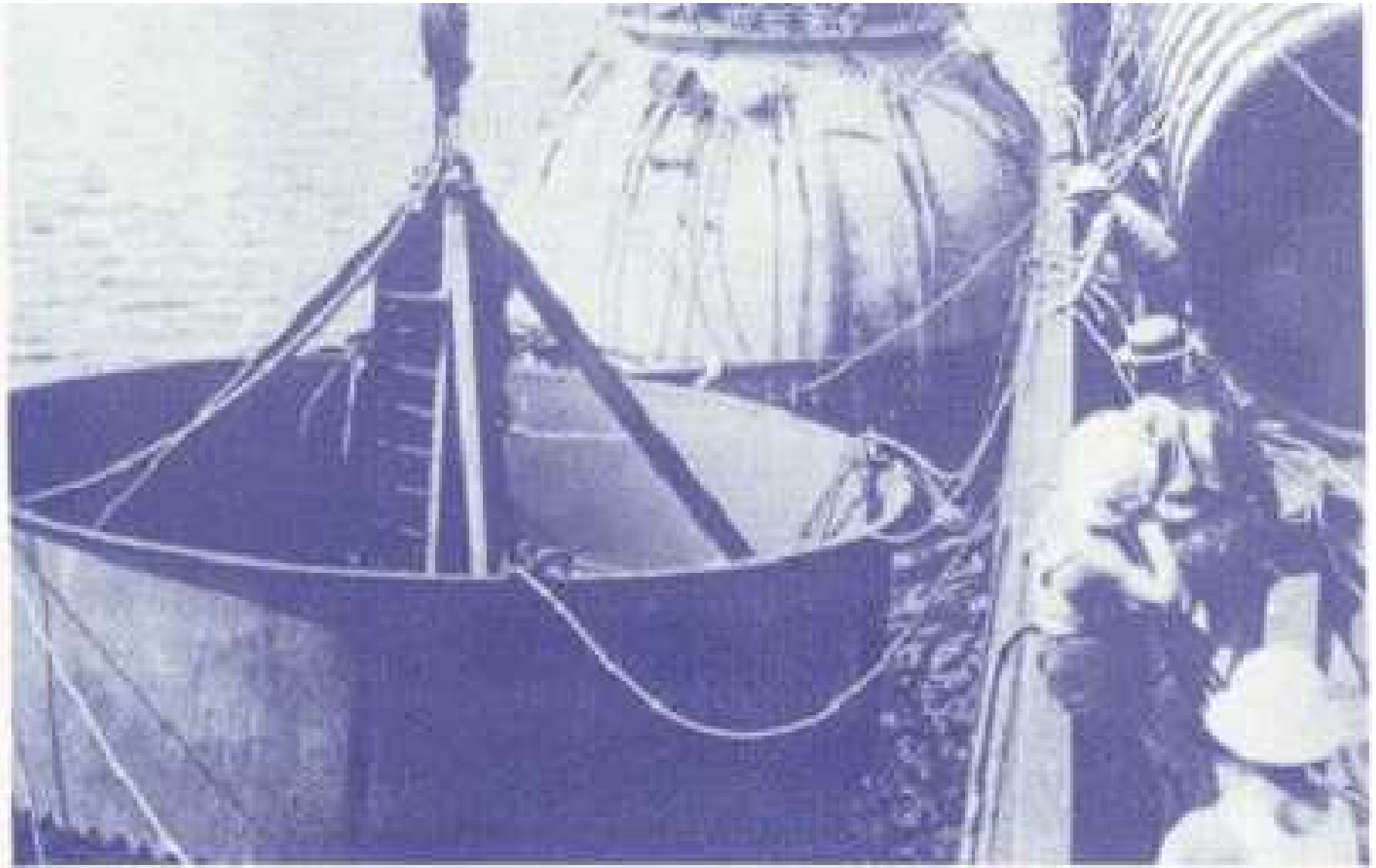
Remnants of Claude's thermal pool in Matanzas, Cuba (1930)

source: Bohemia (Cuba), 2007



Ship "*Tunisie*", where Dr. Claude located his OTEC plant for Brazil in 1935.

CWP lost in storm. *Source: French Wikipedia*



Cold water pipe for Claude's plantship (*source: Club des Argonautes*)

Further work on OTEC

- French Vichy government founds *Energie des Mers* (EDM) society in 1941. Claude is involved. Result: at end of WWII, jailed as Nazi collaborator until 1950.
- EDM continues to be active through 1950's. Designed an OTEC plant for Abidjan (Ivory Coast) but project was too costly.
- EDM ceased operation when French government decided to get heavily involved with nuclear energy.
- In 1950's Norwegian-American engineer Bryn Beorse (who had worked with EDM after WWII) and Professor Everett D. Howe founded the Sea Water Conversion Laboratory at University of California and obtained government funds for research. An open-cycle plant was proposed for water desalination, but government was not receptive. Still, significant research was conducted.

1970's energy crisis

- Due to Arab embargo, oil prices increased steeply, driving world into recession
- President Carter called for energy independence for U.S. (“Moral Equivalent of War”)
- Federal government provided funds for OTEC research.
- Significant amount of work done by private companies, Johns Hopkins APL, Argonne National Laboratory and UPR Mayaguez
- Proposals for a demonstration system were requested by the Department of Energy.
- The Puerto Rico Electric Power Authority (PREPA) was among the proposers and conducted several detailed studies on the feasibility of OTEC.



One of PREPA's Proposals to DOE



AIAA-81-2565
Proposed OTEC Punta
Tuna Pilot Plant

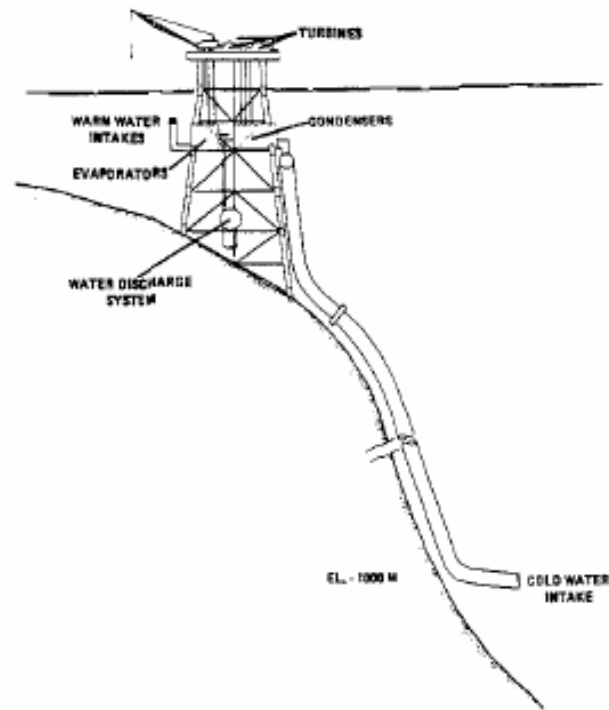
J. Marina and F. Perez, Puerto
Rico Electric Power Authority, San
Juan, PR

AIAA 2nd Terrestrial Energy
Systems Conference

December 1-3, 1981/Colorado Springs, Colorado

Never funded by US DOE

PUNTA TUNA 40 MW Plant (proposed by PREPA in 1979-80)



Federally-funded OTEC work in 1970's to 1990:

- **Multiple experiments on configuration, materials, etc.**
- **Many conducted by UPR Mayaguez**
- **R&D and several system designs funded**
- **Mini-OTEC: an initial prototype system was built by a consortium of private companies using government funds in Hawaii in 1979.**
- **US companies allege this was first time that net production of electric power was demonstrated. However, some reports claim Claude achieved net power generation in experiments at Ougree, Belgium and at Matanzas plant.**





MiniOTEC

(1979)

50 kW CC-OTEC

OTEC 1



- Built in 1980 by DOE
- Test site for closed-cycle OTEC heat exchangers installed on board a converted U.S. Navy tanker.
- Test results identified methods for designing commercial-scale heat exchangers
- Demonstrated that OTEC systems can operate from slowly moving ships
- New design for suspended cold-water pipes was validated at that test site.

Japanese plant at Republic of Nauru

Land-based 100 kW closed-cycle plant



Plant attained net power generation. Downplayed by US companies



210 kW OC-OTEC Experimental Plant



PICHTR, 1993-1998

What happened?

Why OTEC is not in use today?

- **Cost of oil dropped back to \$10/bbl in 1990's**
- **Reagan administration favored nuclear power**
- **Efforts depended on government funding**
- **Federal government (and other nations) stopped most funding for OTEC research in 1990's.**
- **Global warming was known, but did not become a major concern until much later**



Why now?

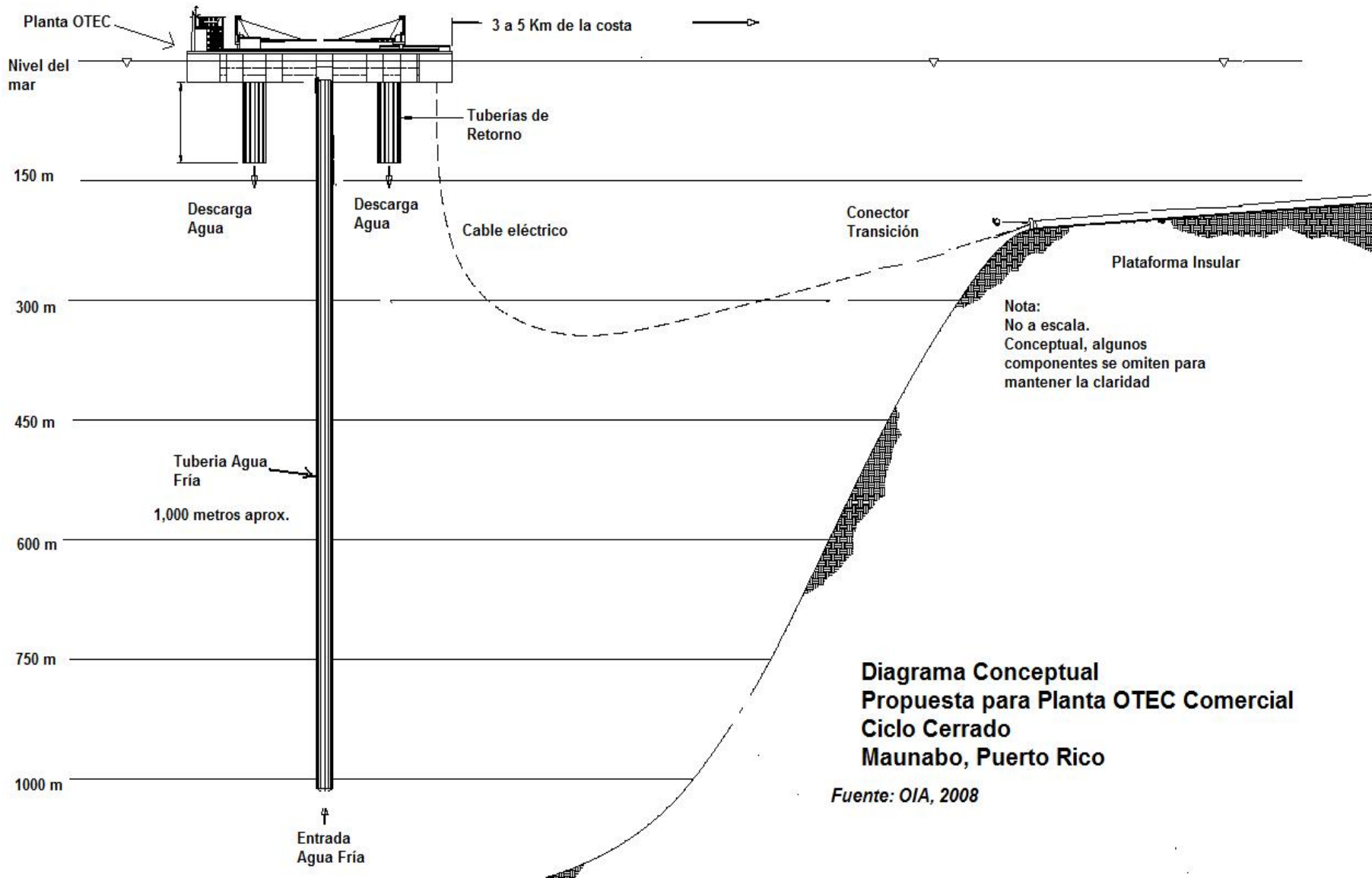
- Oil prices have surged (\$140/bbl, \$5.00/gal gas)
- High volatility of prices
- Concerns about stability of oil supplies and peaking of production
- Increase in oil prices will cause increase in price of other fuels (LNG, Coal, etc).
- Concern about global warming
- Energy-water nexus
- Likely carbon tax or clean energy credits on global basis
- In Puerto Rico, **total dependency on imported energy sources.**



OIA Strategy for Commercialization

1. Use results of research conducted during 1970's to date.
2. Base design on commercially available equipment and manufacturing capabilities. No need to re-invent the wheel
3. Financial strategy based on private funds. No need for Federal grants or local government investment. All required is willingness to use the power to be produced
4. Take advantage of unique conditions available in Puerto Rico:
 - ⇒ Proximity to deep water
 - ⇒ Highly developed society with need for power
 - ⇒ Island is covered by electrical transmission grid
 - ⇒ Highly educated and sophisticated workforce
 - ⇒ Incentives for industrial development
5. Puerto Rico as base for exporting OTEC technology





Concept for Proposed Commercial Powerplant at Maunabo, Puerto Rico



Punta Tuna

TJP's original plant started in 1968

Approximate location of the proposed first commercial OTEC plant in history

En la mira la costa de Maunabo

Sus aguas albergan una potencial fuente inagotable de electricidad

POR RUT N. TELLADO DOMENECH
rutellado@elnuevodia.com

CON EL constante alza de precio de los combustibles fósiles, surge la urgencia de buscar otras opciones para producir energía. Una de ellas está en el mar.

La conversión de energía termal oceánica (OTEC, por sus siglas en inglés) aprovecha la diferencia de temperatura del agua de la superficie del mar que recibe el calor del sol, y el agua fría de las profundidades.

Esa diferencia debe ser de por lo menos 36 grados Fahrenheit para que se pueda generar electricidad, explicó Juan Alicea Flores, asesor en materia de energía del presidente del Colegio de Ingenieros y Agrimensores de Puerto Rico, Antonio Medina Delgado. «Cómo funciona? En una plataforma ubicada en el océano, se utiliza un fluido (amoníaco o freón) que se evapora a una temperatura relativamente baja. El agua de la superficie calienta el fluido hasta convertirlo en un gas que mueve una turbina conectada a un generador para producir electricidad.

Luego, el gas pasará a un condensador, donde el agua fría del fondo marino lo convertirá en líquido. El fluido sería bombeado de vuelta a su punto de origen para utilizarlo de nuevo. Mientras, un cable submarino lleva la electricidad a tierra firme.

Para que se pueda utilizar la OTEC, la plataforma debe ubicar en una zona tropical donde existan grandes profundidades. «Puerto Rico, además de estar en el trópico, tiene un área, a dos millas de Maunabo, donde hay más de 8,000 pies de profundidad», explicó Alicea Flores. «Eso hace de esta zona el sitio perfecto para el desarrollo de esta tecnología».

El ingeniero, quien también es director de Planificación y Protección Ambiental de la Autoridad de Energía Eléctrica, confirmó que la corporación pública está en proceso de desarrollar un proyecto de este tipo en el área maunabeña conocida como Punta Tuna.

De lograrse el acuerdo con la empresa proponente -cuyo nombre no fue revelado-, la instalación estaría lista para el 2013. Alicea Flores estimó que la planta produciría 75 megavatios por hora, lo suficiente como para brindar electricidad a más de 100,000 familias.

POSIBLES RIESGOS

A juicio del ingeniero, una de las ventajas de la energía termal oceánica es que «está ahí 24 horas al día, siete días a la semana, 365 días al año», a diferencia de la energía solar y la eólica, que dependen de que haya sol o viento.

Otro punto a favor de la OTEC es que el impacto al ambiente sería mínimo, afirmó Alicea Flores. Con el coincidir el oceanógrafo físico Jorge Capellas, quien desde la década de los años 70 ha trabajado en intentos previos de introducir esta tecnología a Puerto Rico. «La planta no generaría humo ni utilizaría combustibles fósiles», dijo.

Añadió que, hace 30 años, el riesgo era que el agua del fondo creara nubes de plancton y regara otros nutrientes una vez se utilizara y regresara al mar.

Sin embargo, indicó que diseños más modernos han resuelto el problema utilizando esta agua fría para refrigeración y acuicultura. En Hawái, donde hay una planta experimental de OTEC, el líquido se utiliza tanto en el aire acondicionado como para cultivar algas.

Aunque destacó que otro posible riesgo es el de un derrame de amoníaco o freón, no pudo precisar cómo un evento de este tipo impactaría el ecosistema.

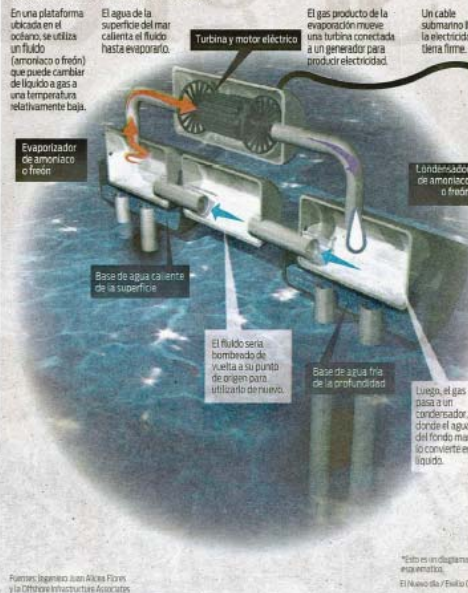
Capellas no dudó en afirmar que las ventajas de la energía termal oceánica superan las desventajas y que «nos resolvería gran parte de nuestra crisis energética en Puerto Rico».

La corriente del mar

¿QUÉ ES LA CONVERSIÓN DE ENERGÍA TERMAL OCEÁNICA?

Ésta aprovecha la diferencia de temperatura del agua de la superficie del mar, que recibe el calor del sol, y el agua fría de las profundidades. Esa diferencia debe ser de por lo menos 36 grados Fahrenheit para que sirva para generar electricidad.

¿CÓMO SE PRODUCE ELECTRICIDAD?



Fuente: Ingeniero Juan Alicea Flores y la Offshore Infrastructure Associates

Renewed projections



“The only realistic way to reduce Puerto Rico’s electricity costs is through a combination of conservation and diversification, including fossil fuels and renewable sources.”
—Jorge Rodríguez, Prepa Executive Director

Director Jorge Rodríguez.

“In our case [Prepa], we will use natural gas, clean coal technology, low-sulfur oil, wind, biomass, waste-to-energy, ocean thermal, landfill gas, solar power and other sources as our portfolio for power generation.”

Currently, there are six major renewable energy projects either underway or under advanced evaluation. Once completed, the combined generation of 2,000 megawatts (MW) will supply roughly one third of Prepa’s current power capacity.

“We are very excited about Prepa’s new energy diversification,” said Fortaleza Chief of Staff Jorge Silva Puras. “We already have two wind-energy farms under development, and a third mega-wind project is in the pipeline that could generate an additional 1,000 MW. Prepa is rescuing the OTEC (ocean thermal energy conversion) technology initiative considered more than 20 years ago, with a project to be located in the southeastern part of the island.”

Yet another exciting initiative underway is OTEC, ocean thermal energy conversion, a way to generate electricity using the temperature difference from the surface to different depths.

“The method involves building a floating platform to pump cold water from the ocean depths to the surface and extracting energy from the flow of heat between the cold water and warm surface water. OTEC utilizes the temperature difference to run an ammonia turbo generator,” explained renowned environmental scientist and project consultant Dr. Michael Szendrey.

“Prepa signed a letter of intent with a project proponent to develop an OTEC initiative with a 75 MW capacity,” said Alicea. “We’ve just received the results of the viability study.”

“There are only a handful of places in the world in which these ideal conditions can be found. Puerto Rico is one of those places,” added Silva Puras. “Successfully developing OTEC technology not only will diversify our fuel production, but will put us on the map at the cutting edge of this important technology development.”

Sabías que...

Ciencia

Al derretirse un hielo flotando en agua, el nivel original del agua no cambia. ¿Por qué entonces nos preocupamos de que se derrita el hielo de los polos de la Tierra? Porque no todo el hielo de los polos está flotando sino que está apoyado del fondo del mar. Si se llena un vaso de agua con hielo y se continúa añadiendo hielos hasta que estos estén apoyados del fondo del vaso (y no flotando), al derretirse el agua se desbordará. ¡Pruébelo!

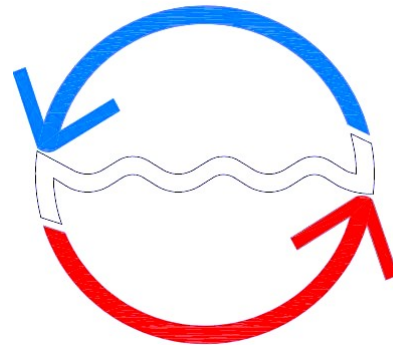
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Recent press reports on OTEC for Puerto Rico

More information?
Copies of presentation?



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