

OCEAN THERMAL ENERGY CONVERSION (OTEC)

Implications for Puerto Rico

Presentation to PRW&EA Annual Meeting
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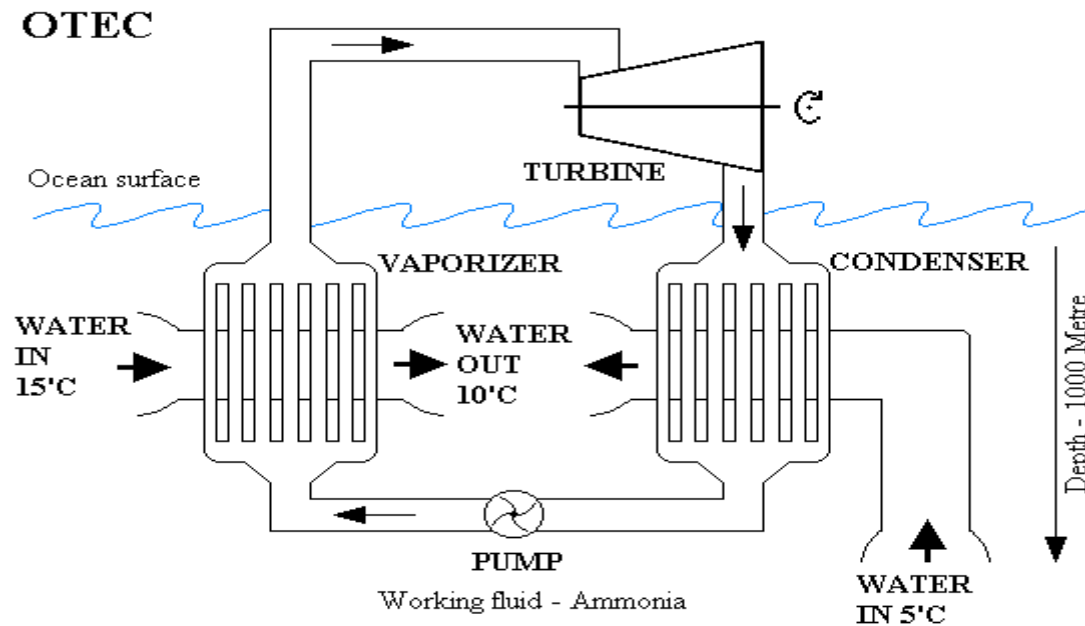
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What is OTEC?

- Ocean 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, on a continuous basis. 0.5 MGD/MWe can be produced, if so desired.
- Minimal environmental impacts as compared to other sources

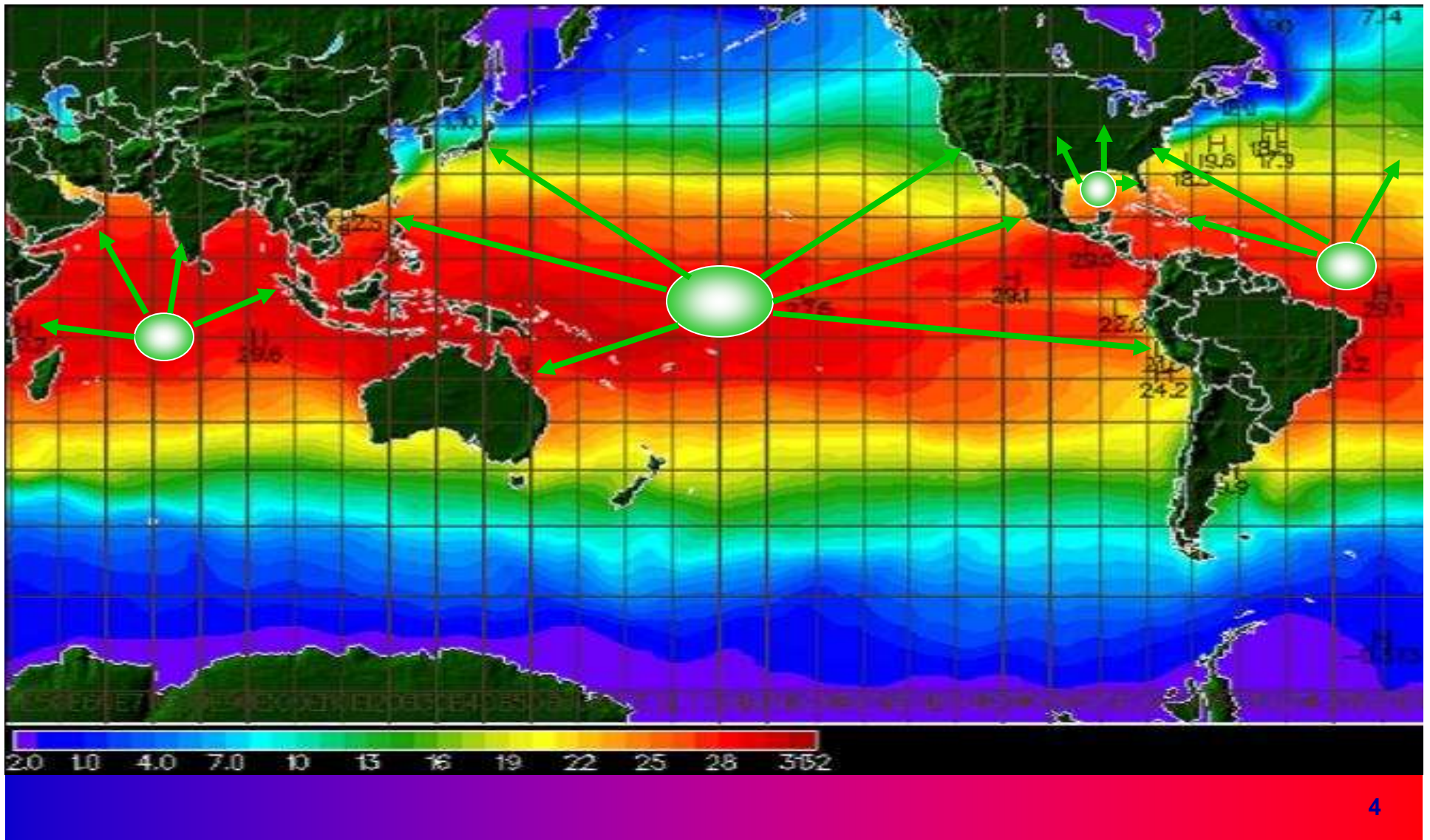
Schematic Description of OTEC



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.

Where will OTEC work?

Tropical and Sub-Tropical regions all over the globe



Best Location for OTEC in the World



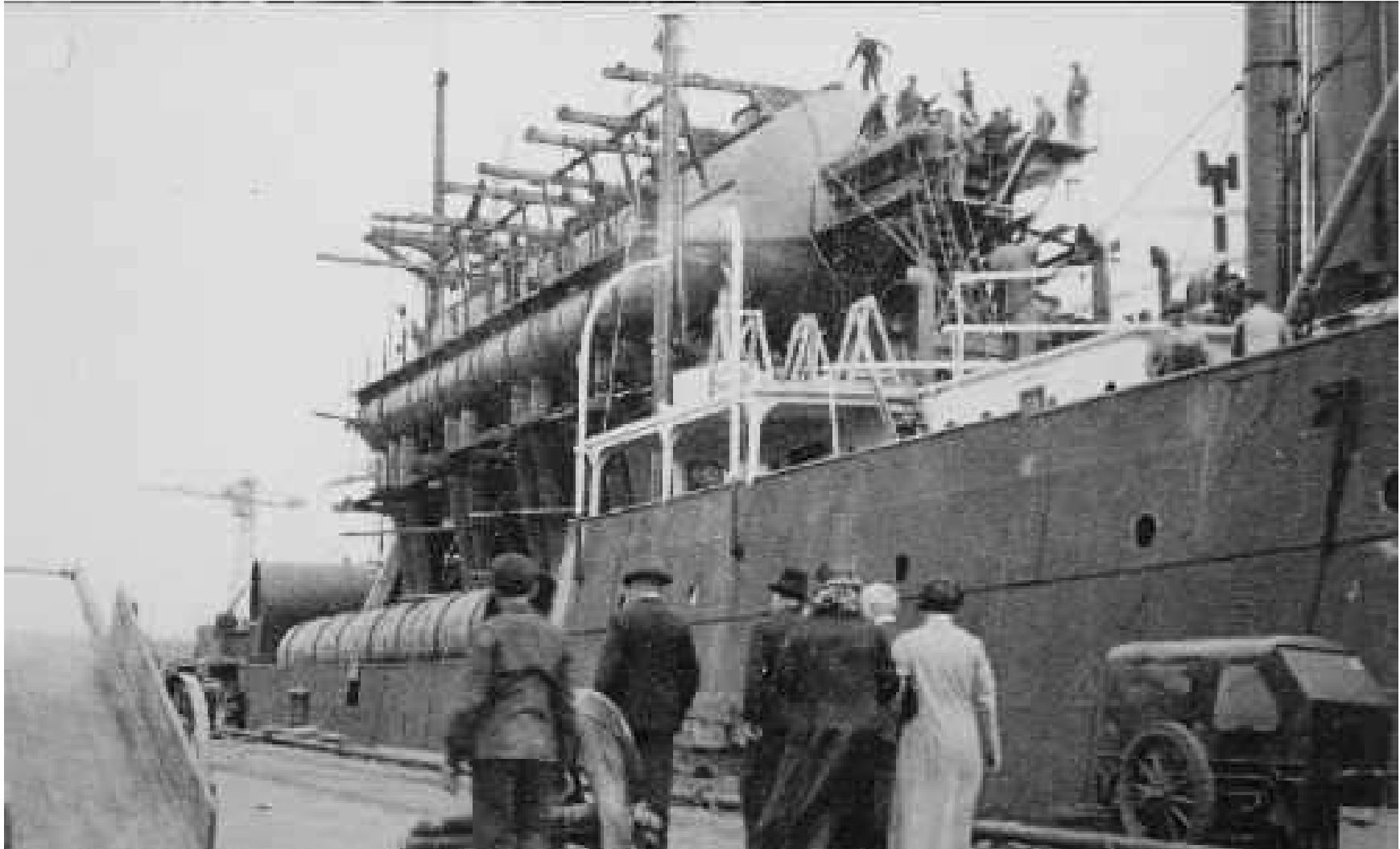
History

- 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, Dr. Georges Claude, who invented neon lighting, built the first plant in Matanzas, Cuba in 1930. On October 6, 1930 Claude's team started a 22 kW generator and lit an array of lamps.
- Plant operated only 11 days, destroyed by storm
- After Cuban failure, Dr. Claude made a second attempt in Brazil, aiming to produce ice. Also failed due to storm.



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.

Also destroyed by storm. *Source: French Wikipedia*

Further work on OTEC

- French government remained interested in OTEC. Work stopped during WWII.
- In 1950's French engineers attempted to build an OTEC plant in Abidjan (Ivory Coast) but project was too costly.
- In 1950's Norwegian-American engineer **Bryn Beorse** 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.

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 Lockheed, 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.
- Efforts centered on Federal funds

One of PREPA's Proposals to DOE



AIAA-81-2565
Proposed OTEC Punta
Tuna Pilot Plant

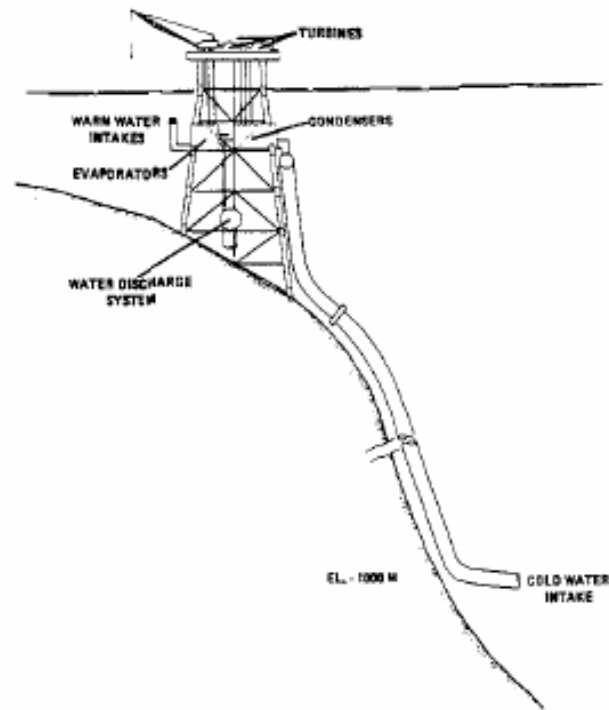
J. Marina and F. Perez, Puerto
Rico Electric Power Authority, San
Juan, PR

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.**
- **American companies claim Mini-OTEC was 1st time that net production of electric power was demonstrated. However, Dr. Claude reported net power generation in 1930 to Cuban, American and European scientific societies.**

**MiniOTEC
(1979)**

50 kW CC-OTEC



OTEC 1

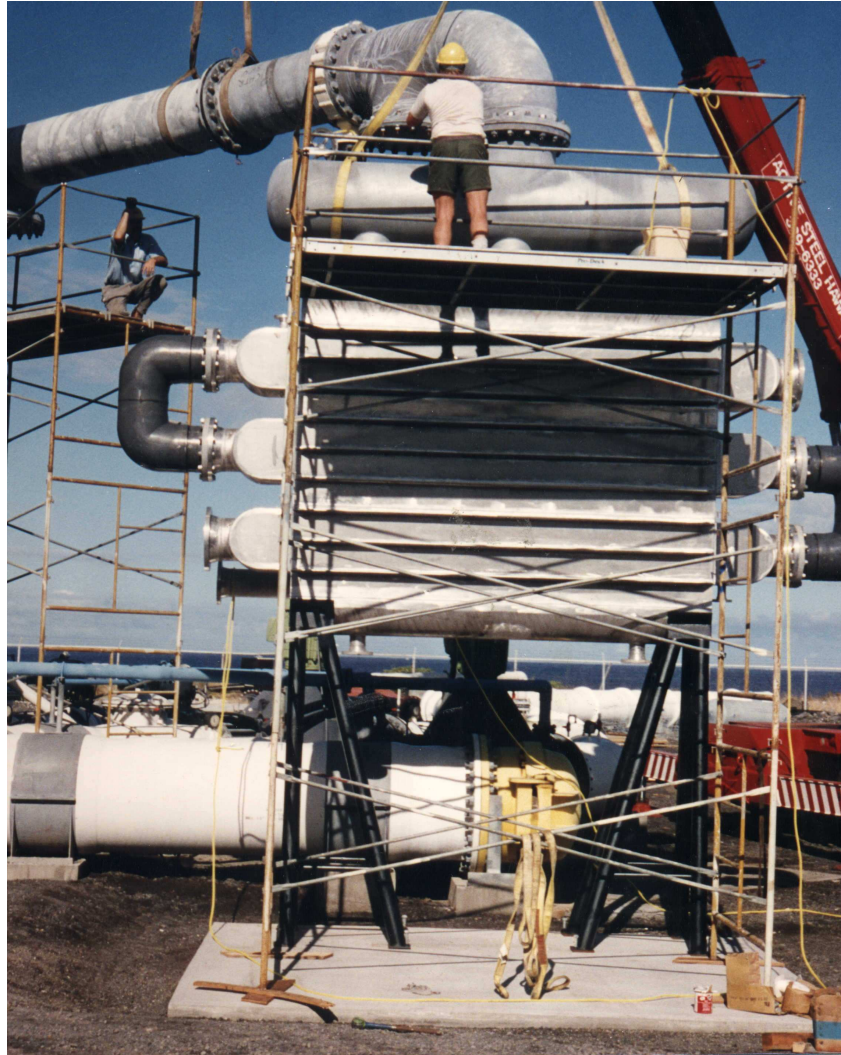


- Built in 1980 by U.S. DOE
- Test site for closed-cycle OTEC heat exchangers installed on board a converted U.S. Navy tanker.
- Test results identified methods for designing commercial-scale heat exchangers
- Demonstrated that OTEC systems can operate from slowly moving ships
- New design for suspended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

210 kW OC-OTEC Experimental Plant



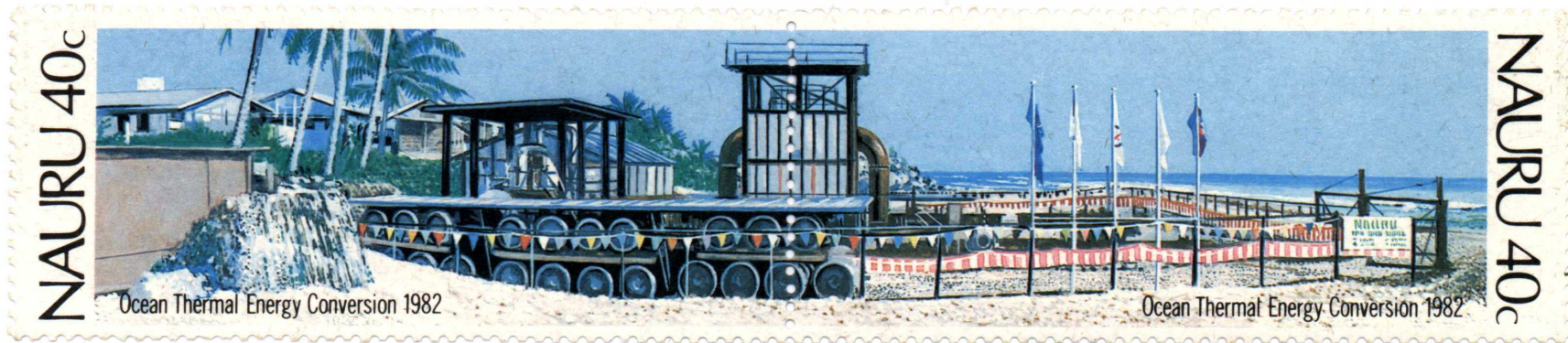
Directed by Dr. Luis Vega: 1993



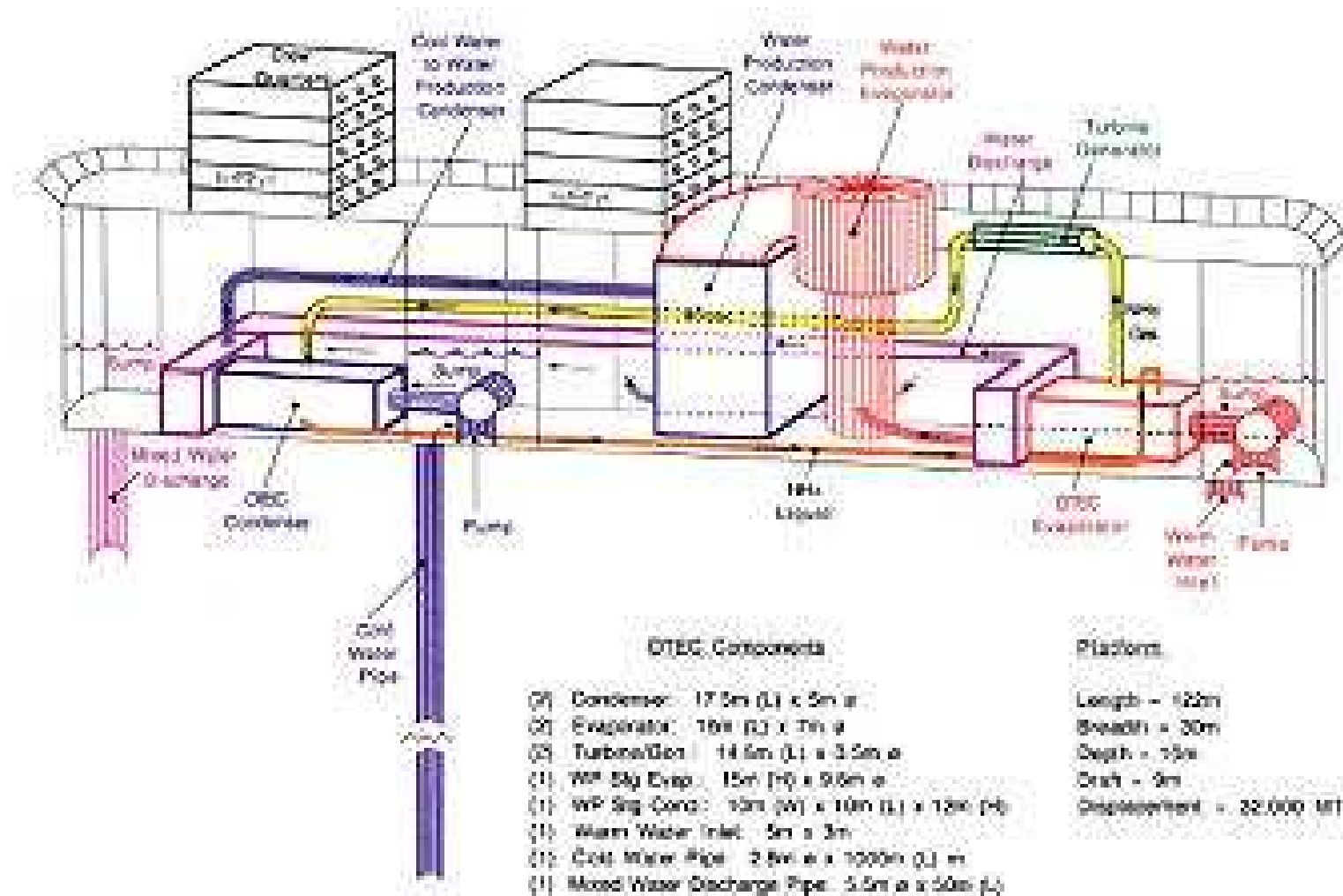
Production of potable water (Directed by L.A. Vega 1994-98)

Japanese plant at Republic of Nauru

Land-based 100 kW closed-cycle plant



5 MWe OTEC Pre-Commercial Plant



Conceptual design by Dr. Luis A. Vega

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. Everyone expected Uncle Sam to foot the bill.
- Federal government (and other nations) stopped most funding for OTEC research in 1990's.
- Global warming not a major concern until much later

Why now?

- Oil prices have surged (\$135/bbl, \$6.00/gal gas)
- 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.

OTEC Environmental Impacts

- No fuel needed
- No emissions of conventional air pollutants
- No solid wastes
- Discharge essentially similar to ambient water
- **Can concurrently produce potable water**
- Stable supply- not vulnerable to external factors
- Very high availability factor.
- **Cost is known and fixed from day 1.** Very low volatility
- Public tends to be receptive to idea, once the basic principle is understood.

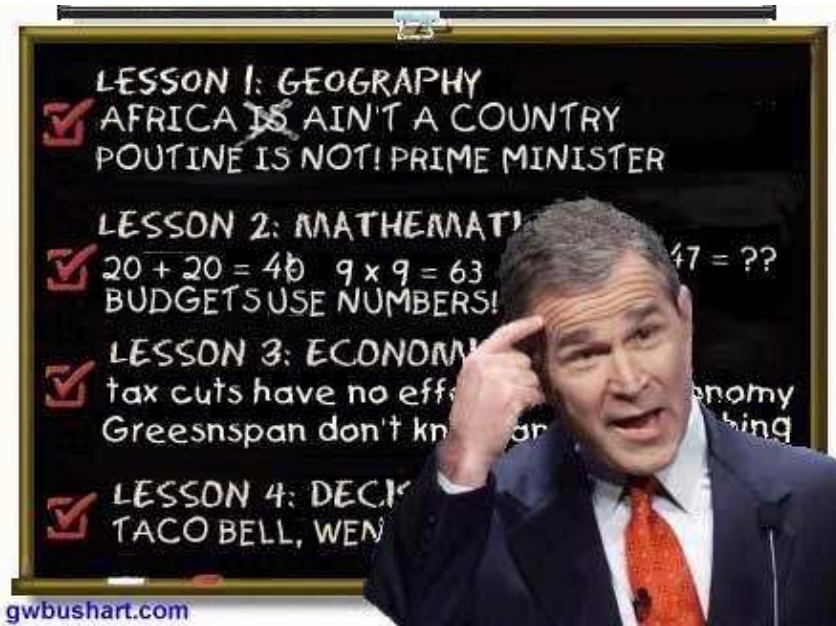


Socioeconomic Aspects

- As important as environmental aspects.
- Lack of stable and reliable energy source can cause major social and economic disruptions, and even lead to wars.
- Japan used concerns about oil supplies as an excuse to attack US in WWII.
- Current economic downturn directly tied to high energy prices



Energywise, PR is at the mercy of outside factors:



We have no control over actions of any of these gentlemen.

Potential major risk for Puerto Rico



Repeated border incidents between Colombia, Venezuela and Ecuador may lead to regional war involving major fuel suppliers for Puerto Rico.

Socioeconomic Effects

- Energy price surges have social effects.
- Puerto Rico has no control over energy costs.
- Lack of control discourages productive activities and investments, magnifying the economic impacts of energy costs.
- General mood of despair extends to all parts of society and transcends realm of economics.
- Multiple social problems: crime, mental health, political instability, corruption, etc.



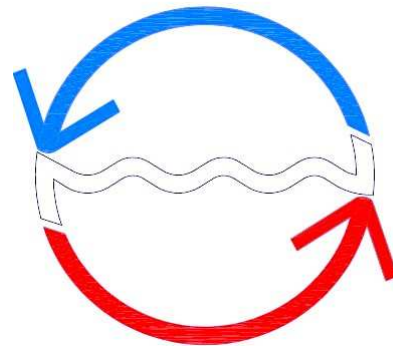
Theoretical Plan for Implementation in Puerto Rico

- Initially, one or more plants for PREPA for power generation only, on floating platforms (75 to 100 MWe each)- Southeastern Puerto Rico
- Power cost: comparable to \$55/barrel oil
- Possibility of small land-based plants for PRASA with co-production of power and water (2 to 5 MWe, 0.5 MGD/MWe). Same cost, plus value of water.
- Private funding for first units, no financial risk to government.
- PRASA/PREPA joint effort?
- Public private partnership?
- Eventually, OTEC can be major source of power for Puerto Rico, handling baseload consumption.
- Export of OTEC services can provide input to economy.

Conclusion

- OTEC is the most benign and less risky form of generating large amounts of energy presently available
- Available 24/7/365
- Not vulnerable to external factors (embargos, wars, demand hikes, etc)
- Fixed and known costs from Day 1.
- Usable for critical baseload in systems
- Can generate potable water, if so desired.
- PR can be base for OTEC companies.
- Can lead Puerto Rico towards energy independence.

More information?
Copies of presentation?



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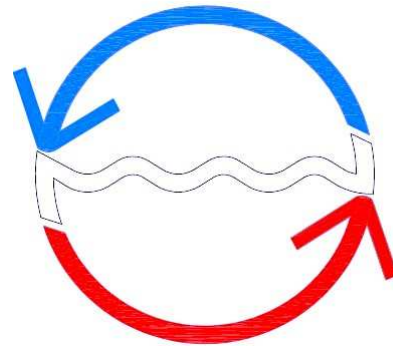
www.offinf.com



OTEC Video

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