OCEAN THERMAL ENERGY CONVERSION (OTEC)

Commercial Implementation and its Implications

presented by:

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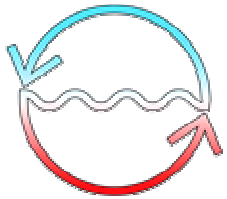

Institute of Electrical and Electronic Engineers (IEEE)

Puerto Rico Section
April 24, 2008

OTEC:

History and Basic Concepts

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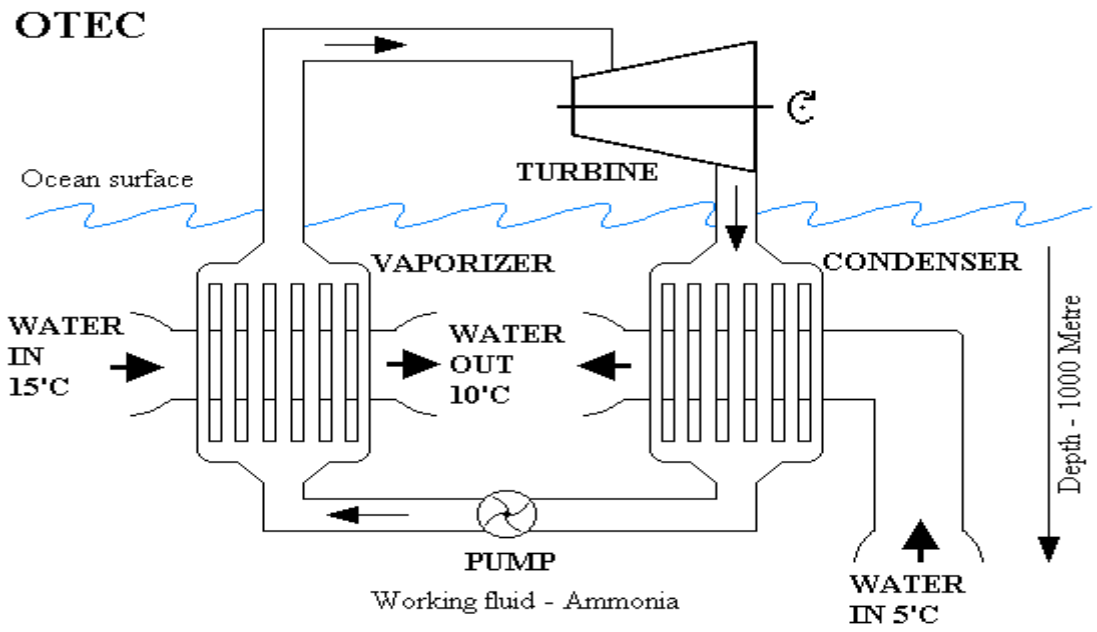
What is OTEC?

- 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

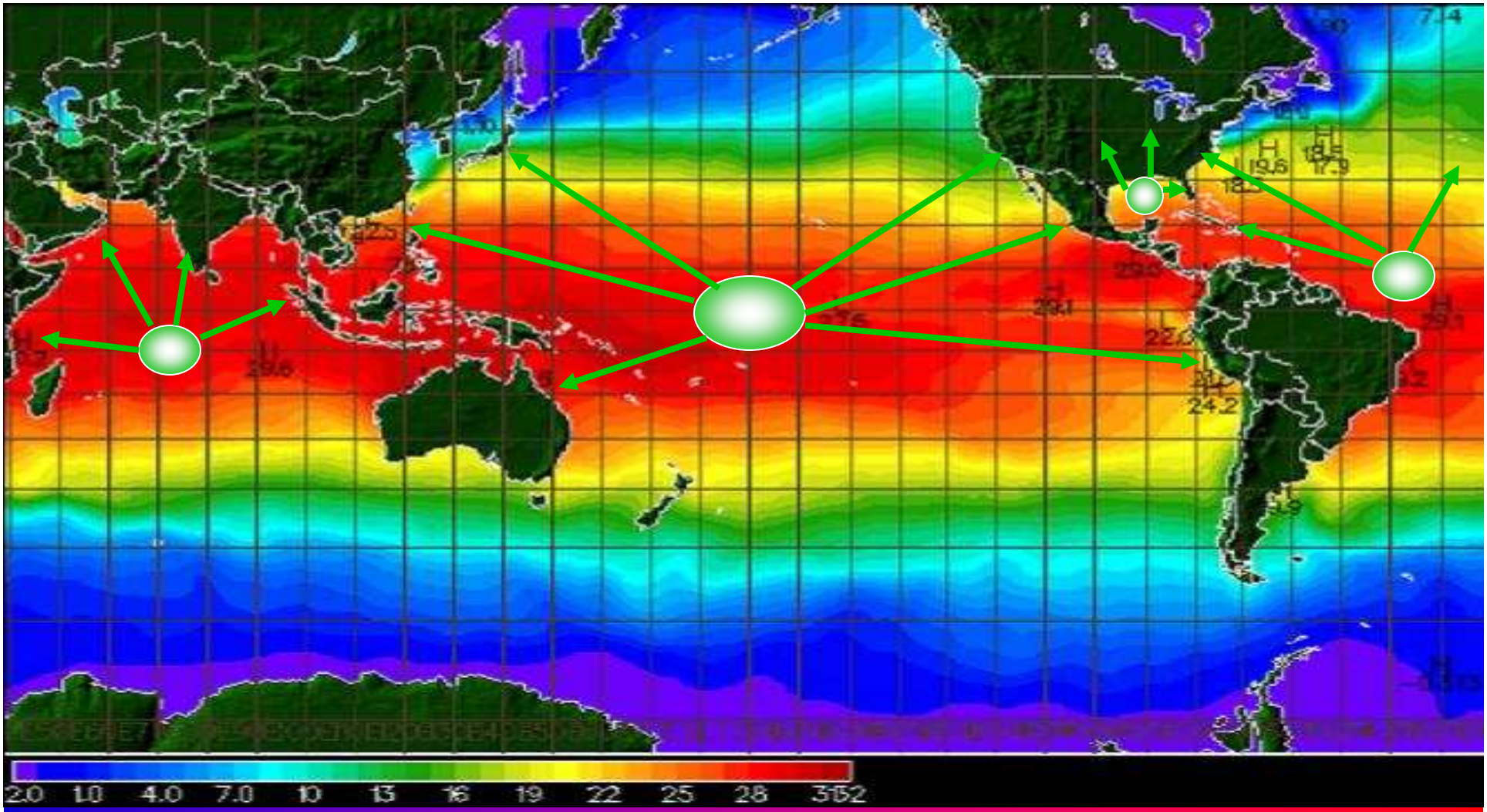
Schematic Description of OTEC



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.

Where will OTEC work?

Tropical regions all over the globe



OIA OTEC MOVIE

Provides basic information about OTEC

History

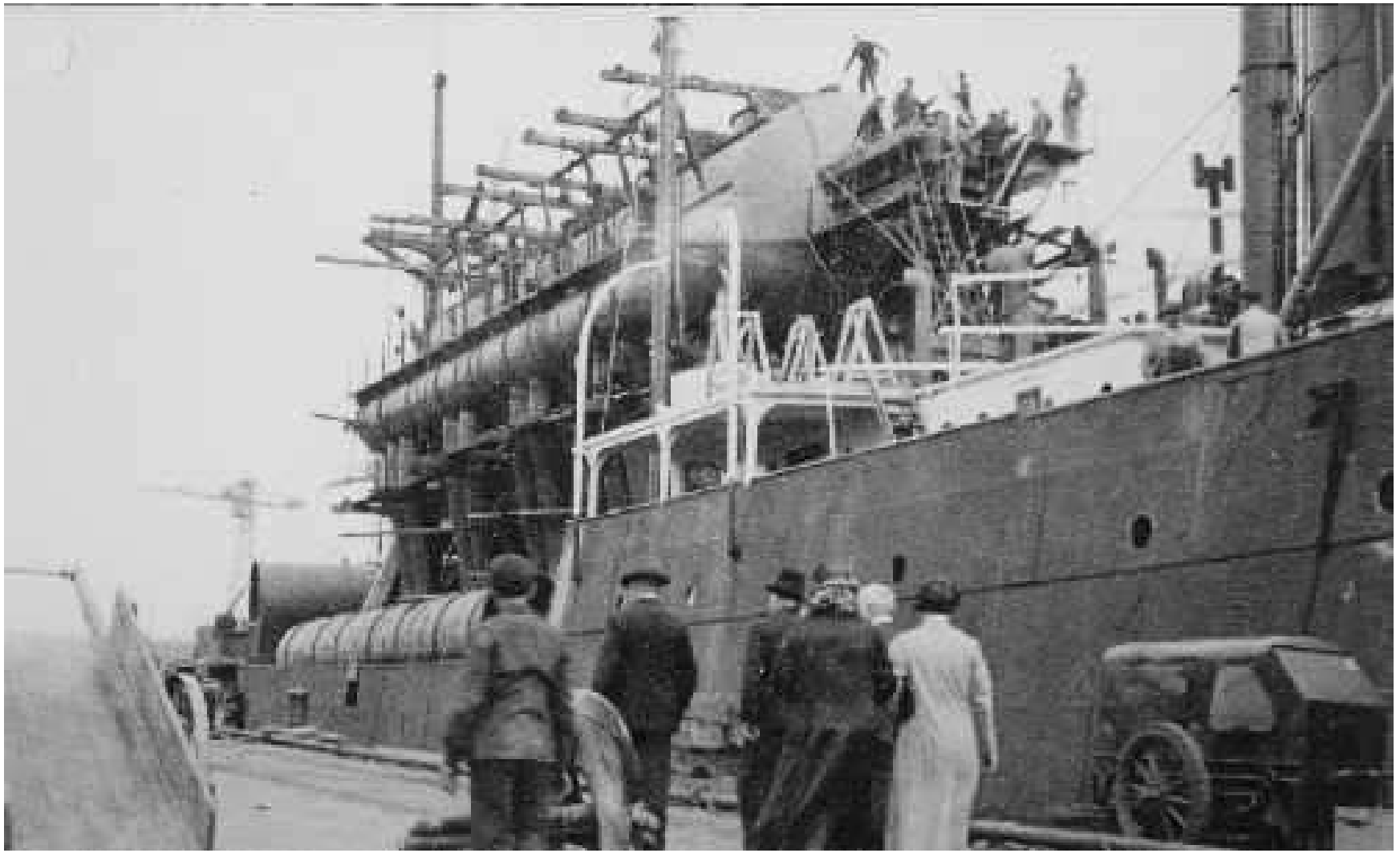
- Idea conceived by Jules Verne in *20,000 Leagues Under the Sea,* published
- Jacques D'Arsonval formally proposed the idea in France in the 1880's.
- His disciple, engineer/entrepreneur Dr. Georges Claude, who improved the air liquefaction process, and invented neon lighting, built the first plant in Matanzas, Cuba in 1930.
- Major problem: Climate. There are no tropical weather systems in France...

Claude's Initial Work

- 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 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*

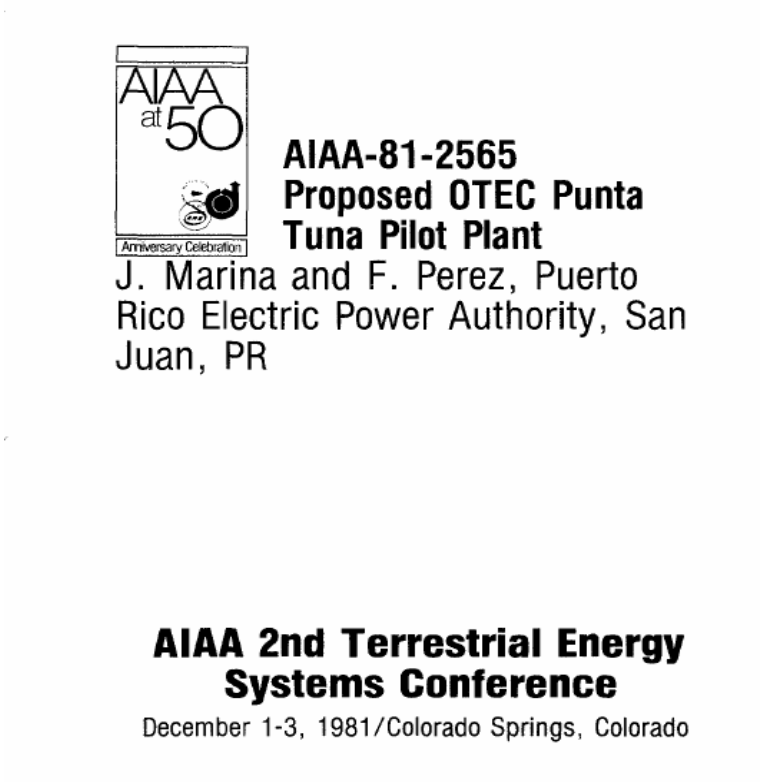
Further work on OTEC

- 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

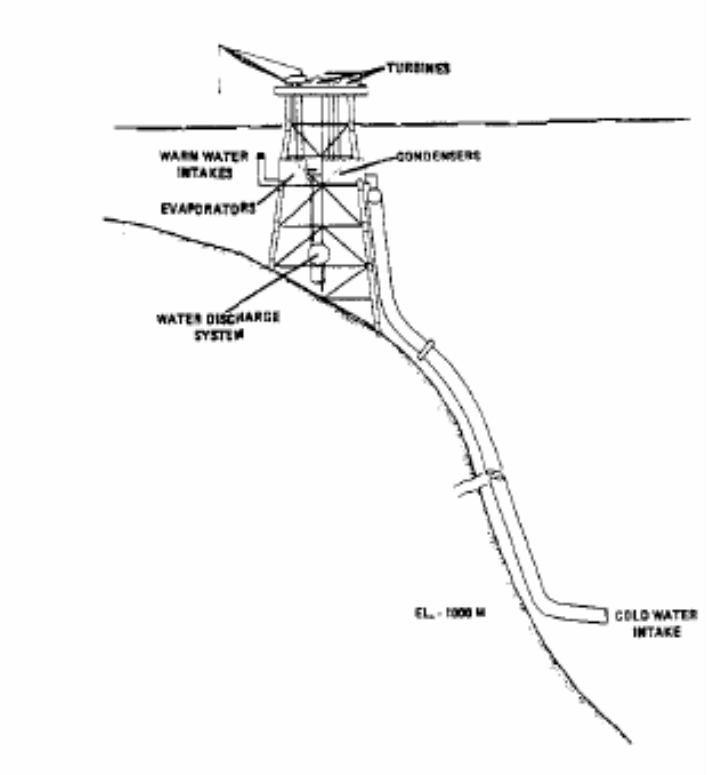
- Due to Arab embargo, oil prices increased steeply, driving world into recession
- President Carter called for energy independence for U.S. ("Moral Equivalent of War")
- Federal government provided funds for OTEC research.
- Significant amount of work done by Lockheed, Johns Hopkins APL, Argonne National 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.

One of PREPA's Proposals to DOE



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.
- First time that net production of electric power was demonstrated.


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.
- Drs. Luis Vega and CB Panchal were key team members.

50 kW CC-OTEC (NH_3) Test Apparatus

Source: Vega, 1999

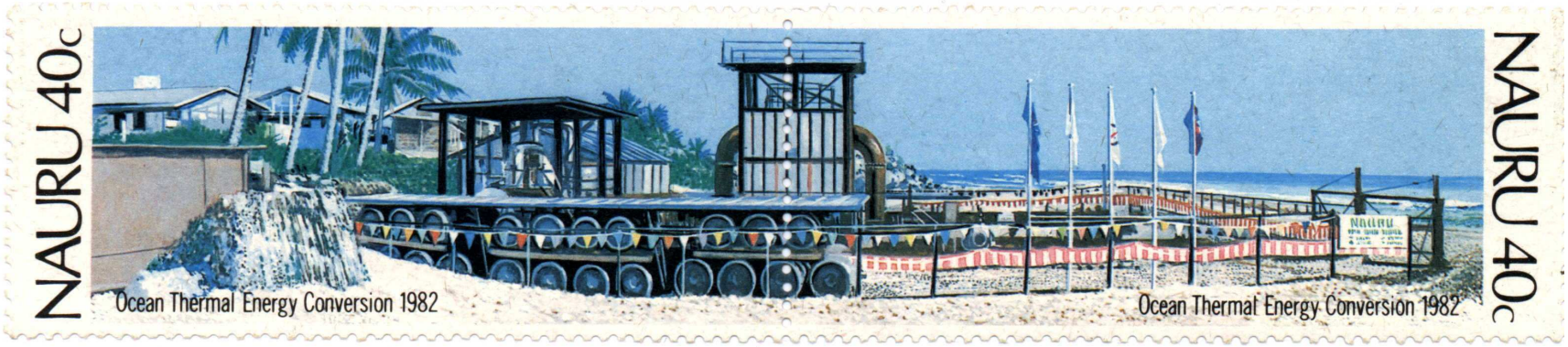
210 kW OC-OTEC Experimental Plant

Vega: 1993

Production of potable water (Vega 1994-98)

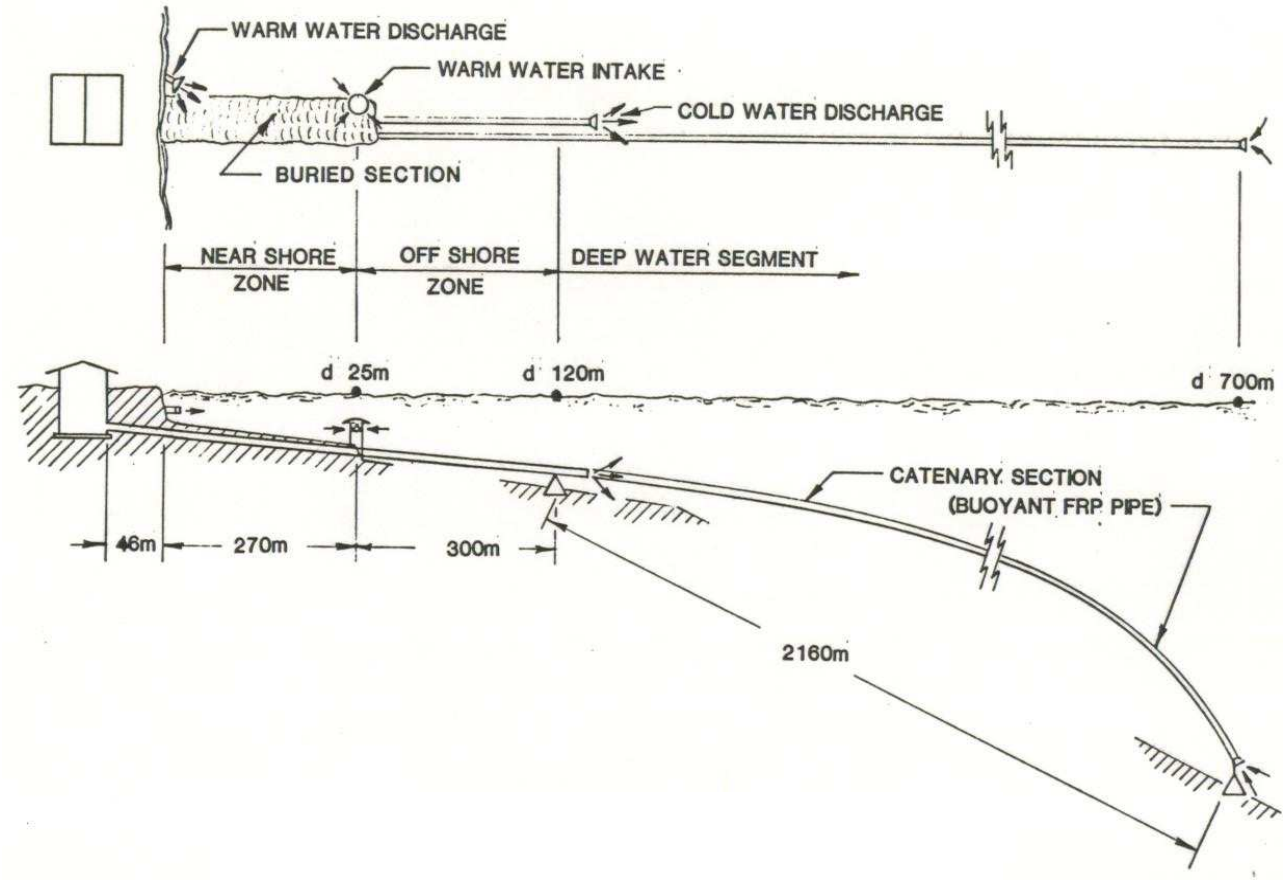
Japanese plant at Republic of Nauru

Land-based 100 kW closed-cycle plant

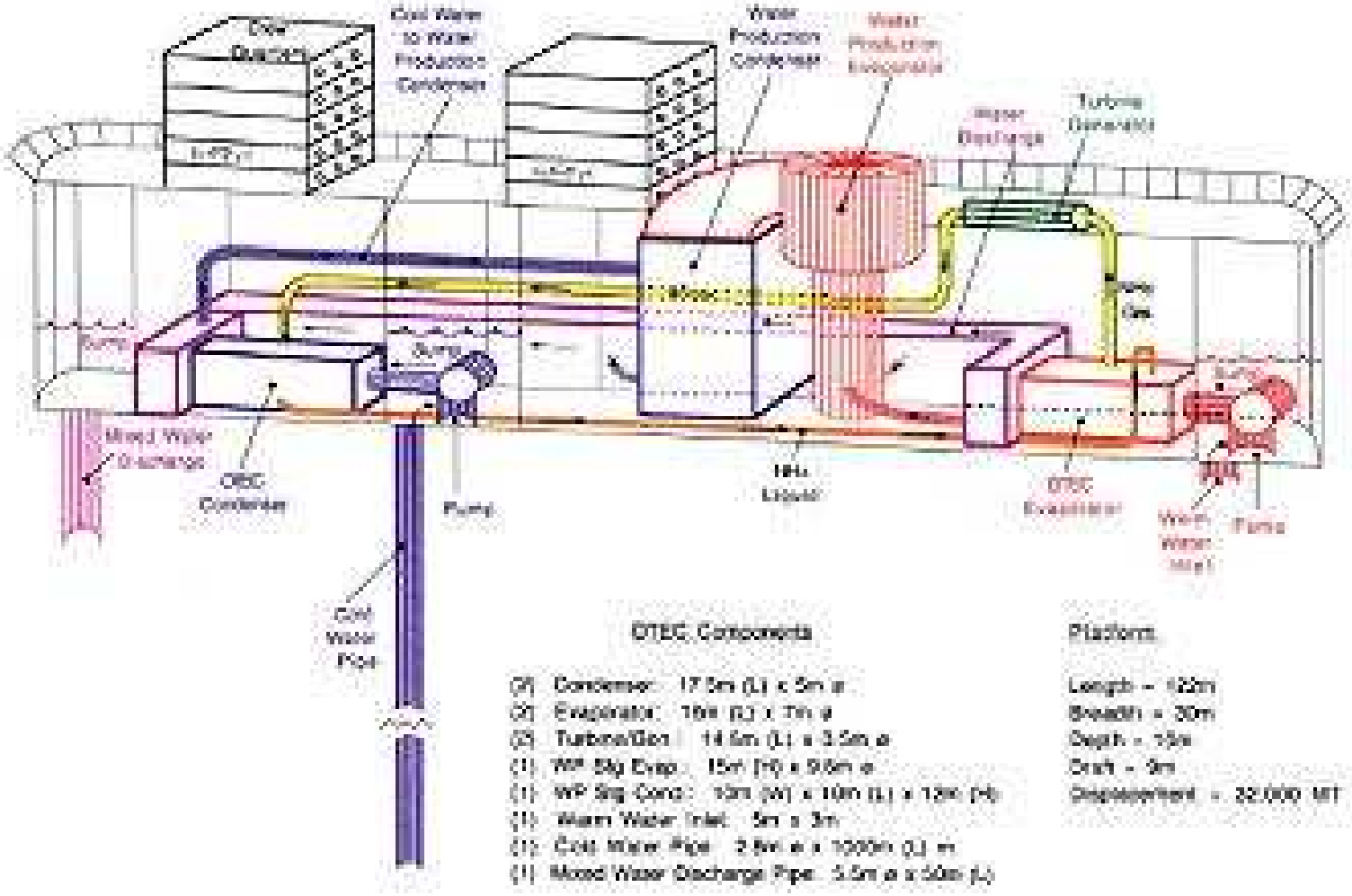


Seawater Systems

Land-Based Small Ocean Thermal Plants



5 MWe OTEC Pre-Commercial Plant



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
- 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 ($120/bbl, $5.00/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.

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