Ocean Thermal Energy Conversion (OTEC)

Viability of Commercial Implementation in a Post-Fukushima World

Presentation to

2011 Low Carbon Earth Summit
Dalian, China

José A. Martí, PE, DEE
Offshore Infrastructure Associates, Inc.

www.offinf.com

What is OTEC?

- A quick review (at the risk of being repetitive):

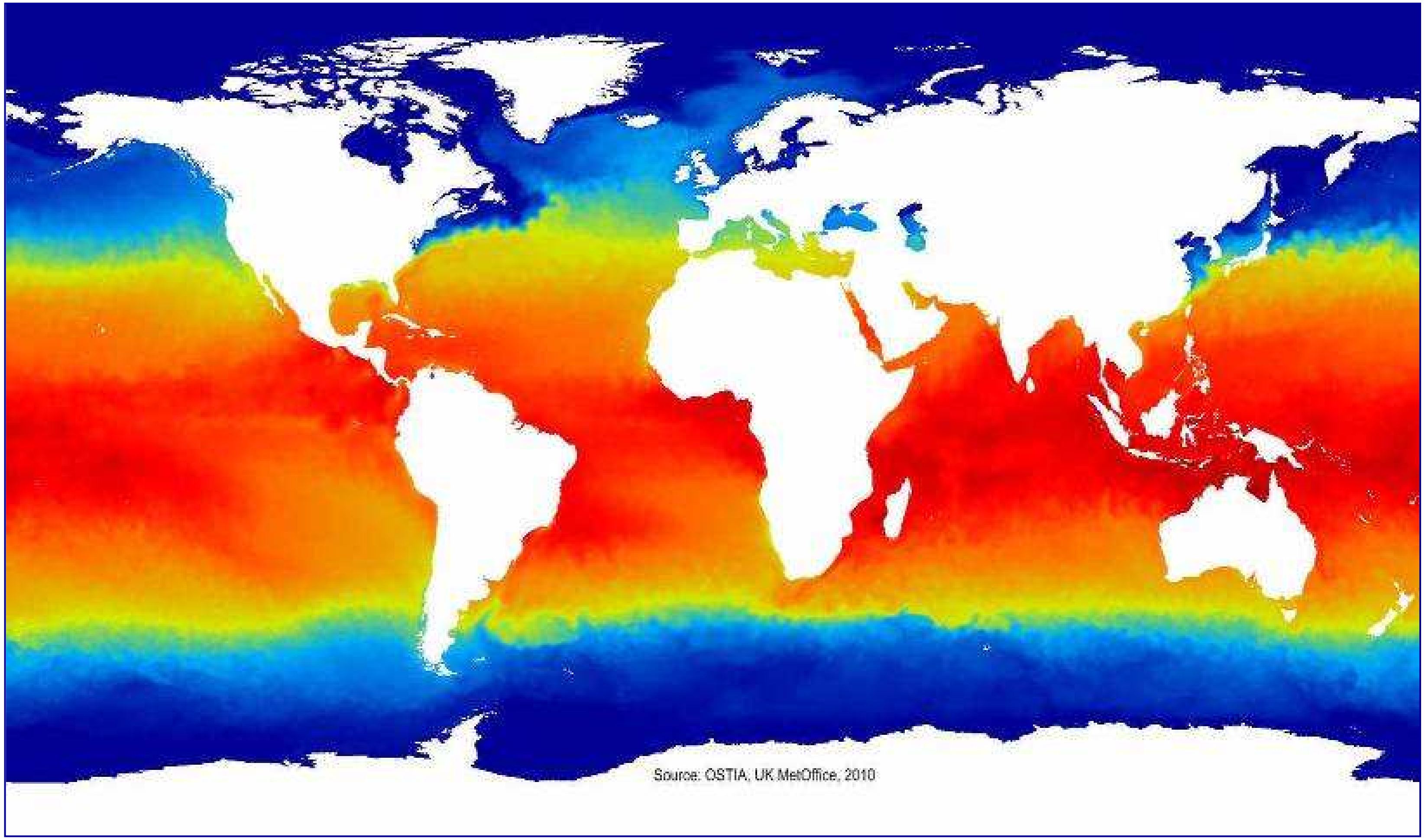
- Ocean Thermal Energy Conversion (OTEC) is a **solar technology** for renewable energy generation.

- Works by recovering solar energy received by the oceans **(ocean is used as a solar collector)** by using temperature differential between warm surface water and cold deep water, in locations where temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about **20°C or higher**. These are **tropical areas** with **deep ocean waters.**

- OTEC allows production of electricity (and desalinated water, if desired) from **local sources** at a **fixed cost**, on a **continuous (baseload) basis.**

Where will OTEC work?

Tropical and Sub-Tropical regions all over the globe



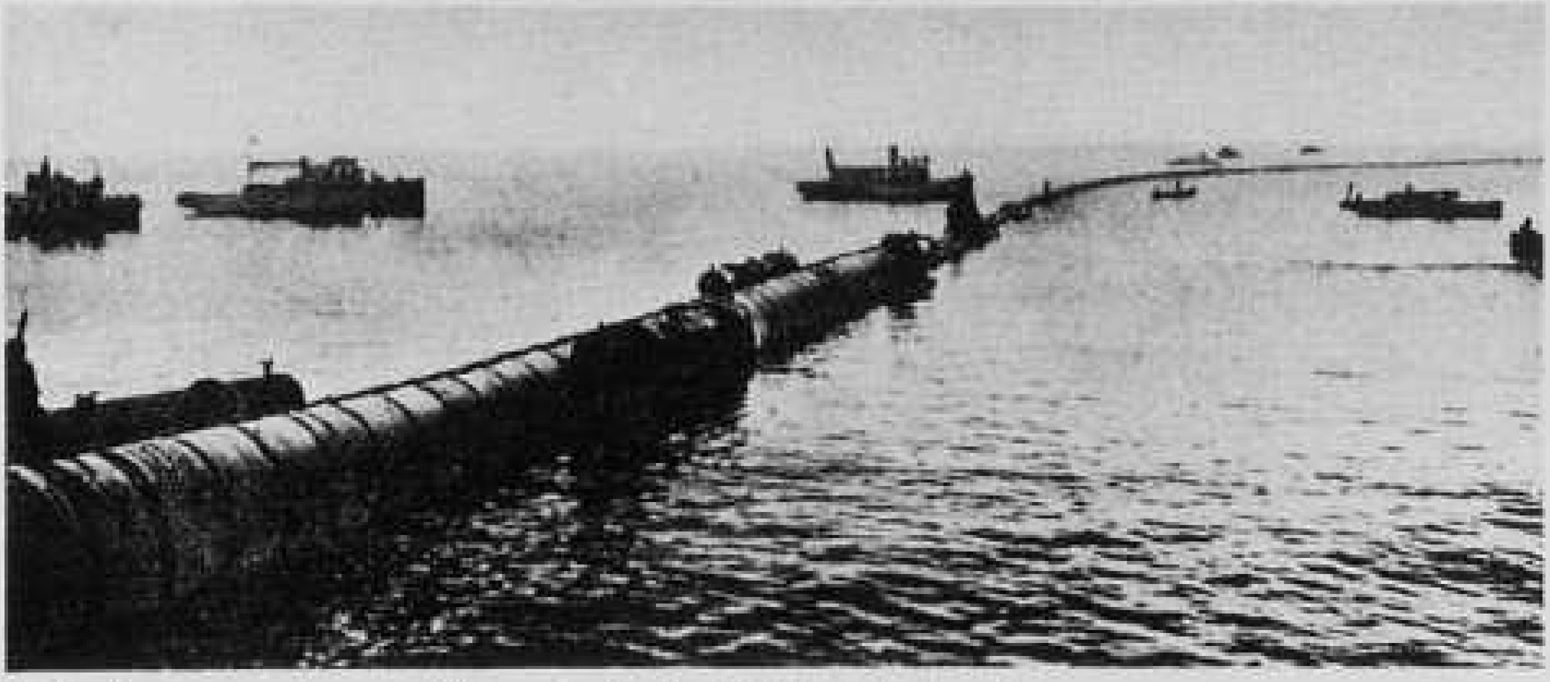
Brief History Review

- 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, conducts experiments in Ougrée, Belgium. Due to good results, first plant is built in Cuba in 1930. Plant runs for a few days and is lost in storm. A second attempt using a ship in Brazil is also lost due to storms.
- Dr. Claude's obsession with OTEC cost him his fortune, freedom and almost his life.

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[1]

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,[2] 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.

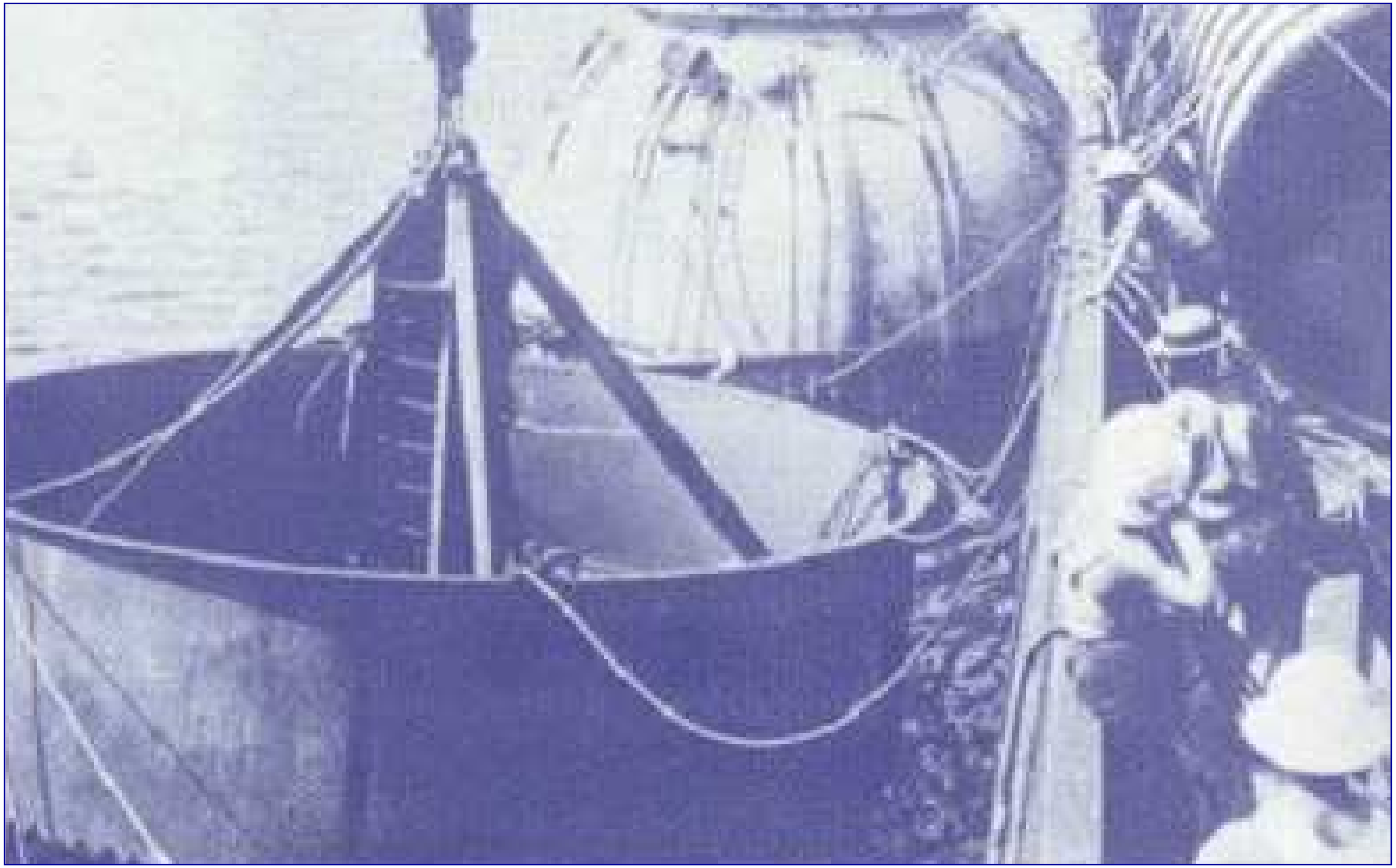
First of all, let me explain exactly what we have been trying to do. We have not been endeavoring to extract power from the waves, from the tide, from streams. What we had in mind, and friend D'Arsonval as far back as 1882, followed by the American engineer Campbell, and the Italian engineers Dornig 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 heat-

Claude reports on Cuban OTEC experiment, 1930

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

source: Bohemia (Cuba), 2007



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

What happened?
Why OTEC is not in use today?

- Cost of oil dropped back to near $10/bbl in 1990's.
- Efforts depended on government funding.
- Most governments stopped funding OTEC research in 1990's, as a result of drop in oil prices.
- Global warming was known to environmental specialists, but did not become a major concern until much later.
- OTEC never analyzed from a utility perspective.

Where are we now?

- **Nobody doubts OTEC is <u>feasible</u> from engineering and scientific standpoints. Still, there are two basic schools of thought:**
- **(1) Treat OTEC as aerospace or defense project, with corresponding R&D efforts, citing need to improve components and/or technologies. Essentially, business is securing external (principally government) funding for more and more R&D. Low thermal efficiency of OTEC is used to justify this approach.**
- **(2) View OTEC from a <u>utility perspective</u>. Determine if a plant designed and built using currently available technology would be <u>commercially viable</u> (reliably generate power that can be sold at a rate sufficient to cover costs and generate a reasonable return to investors).**
- **Basic decision: are we going to use OTEC as a source of R&D funds or as a source of power that can be sold commercially?**

EXAMPLE #1
(Building Construction)

Empire State Building was designed in 1920's and completed on May 1, 1931, using knowledge and techniques available at the time. Still in very successful use today.

EXAMPLE #2
(Power Industry)

- First research nuclear reactor was built in 1942.
- First reactor that generated electric power was EBR-1 (100 kW), built in 1951
- First real commercial nuclear reactor was **Calder Hall**, built in England in 1956, with capacity of 50 MW, later expanded. Operated successfully for 47 years.

Facts:

- ESB and Calder Hall were built with knowledge, materials and techniques available at their times. Both have had long service lives.
- Both served as drivers for further development in their respective fields.
- If the extreme R&D approach some advocate for OTEC had been followed, both projects would not have been built until much later, if at all.
- OTEC for power generation can be implemented now using the same approach used in these two examples. No significant technical barriers, particularly in the case of closed-cycle OTEC.

Key to OTEC commercialization

- Economic viability: the real reason why commercial OTEC plants have not been built is economic: other sources of energy were more convenient and less expensive.
- OTEC powerplants must be analyzed as utility projects. Using an aerospace or defense-type project approach is not appropriate for commercial power generation.
- For an OTEC (or any powerplant) to be commercially viable, it must be able to sell its output at a price that will cover costs and provide reasonable return to investors. It must also be able to do so at equal or lower cost/kWh than other sources. **This is the real key to OTEC commercialization**.
- Environmental impact is important, but often not taken into account by policymakers. **Cost has historically been the main driver in utility decisions,** but recent events are changing this.

CURRENTLY

- **Oil prices have surged ($148/bbl in mid-2008).**
- **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).**
- **Energy-water nexus.**
- **General awareness about global warming. LCES is an example, could not have happened 10 years ago.**
- **Carbon tax, cap on GHG emission or carbon credits on global basis.**
- **Many developing countries are totally dependent on imported energy sources.**
- **Volatility of energy prices is a major concern. Every time oil prices surge, a recession follows.**

Impact of Global Climate Change

- Power generation with combustible fuels is a major source of greenhouse gases (GHG's)
- "Biofuels" and natural gas still generate GHG's when burned.
- Most alternative sources of energy (solar, wind) do not generate baseline power
- Renewed interest in nuclear power.
- James Lovelock ("Gaia") openly endorses nuclear power. "*Nuclear power is the only green solution*".
- Proposals for constructing nuclear plants in island and coastal areas revived after 2005.

2011 Fukushima Accident

- Showed possible cataclysmic effects of a nuclear plant failure. Consequences can transcend national borders, with harm possible at regional and even global level.
- Evidences the danger of building nuclear plants in coastal areas subject to seismic events and tsunamis, particularly in islands.
- Essentially shows **nuclear power is not an option for most island nations.**

Key factors for OTEC commercialization

- Public policy decision to reduce use of fossil fuels
- Commitment to use plant output for a sufficient time to amortize the investment (long term contract)
- **<u>Ability to secure financing at favorable terms and conditions</u>**:
  - Interest rates and terms of financing are key. A 10 year amortization at 11% APR is probably not feasible, a 30 year one at 3% APR likely is.
  - Important: power prices are known for the duration of the contract.
- Given these factors, **OTEC is commercially viable today** for **<u>select locations</u>** presently dependent on oil, and vulnerable to oil price volatility and supply instability.
- Emission credits and taxes can sweeten the deal, but really may not be a critical factor in long-term energy policy decisions, laws can change and credits can be eliminated.
- **Nuclear power- not really a competing factor after Fukushima.**

Conclusions

- Closed-cycle OTEC for power generation is feasible today.
- Principal reason why commercial OTEC plants were not developed in the past was economic (energy from other sources was available at lower costs), not technical.
- Fukushima shows nuclear power is not an option for the locations most suited to OTEC.
- With current oil prices and expected carbon taxes, **OTEC is commercially viable today** for tropical locations that presently depend on oil for baseline power generation.
- Commercial OTEC will be in place within next 5 to 7 years
- Initial generation of plants will be closed cycle.

More information?
Copies of presentation?

Presentation (c) OIA, Inc. 2011

www.offinf.com