Boulder Rotary Club — Sept. 11, 2009

OCEAN THERMAL ENERGY

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Ocean Thermal, a Potentially Vast Source of Renewable Energy
FROM ***the Oceans,***
to Replace Energy from
ACROSS ***the Oceans***

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TOPICS:

- The Resource & the Technology
- Market Applications & Costs
- Engineering Requirements & Challenges
- Environmental Aspects
- Commercial Status of the Technology

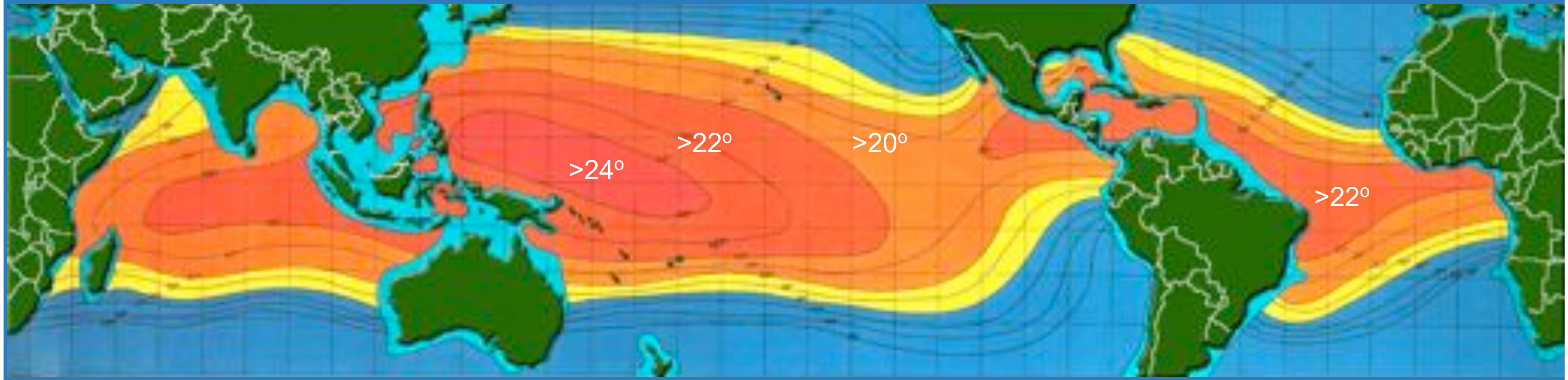
The Ocean Thermal Energy Resource

NATURE PROVIDES AN INCONSPICUOUS, YET VAST, OCEAN THERMAL ENERGY RESOURCE

- Solar radiation is naturally collected by the world's oceans and converted to heat stored in the mixed layer
- The temperature of this heat source is constant 24/7, but varies seasonally
- A heat sink of very cold seawater is naturally available in the major oceans at depths of about 1 km.

In 1881 d'Arsonval pointed out that electricity can be generated from the temperature difference between the oceanic heat source and the oceanic heat sink

Global Map of the Ocean Thermal Resource



Contours of annual average temperature differences (ΔT's), in degrees Celsius, available in the world's major oceans between surface waters (heat source) and the cold water at 1,000 meters depth (heat sink)

Geographical Accessibility of Ocean Thermal Energy

- ***DIRECT:*** Generate electricity and cable it to shore
- ***INDIRECT:*** Generate electricity, convert it to other forms of energy aboard factory ships ("plantships"), and transport the stored energy to shore as:
  - Energy Carriers (such as hydrogen and ammonia)
  - Energy-Intensive end products (such as ammonia for fertilizer, other chemicals, metals, and fresh water)

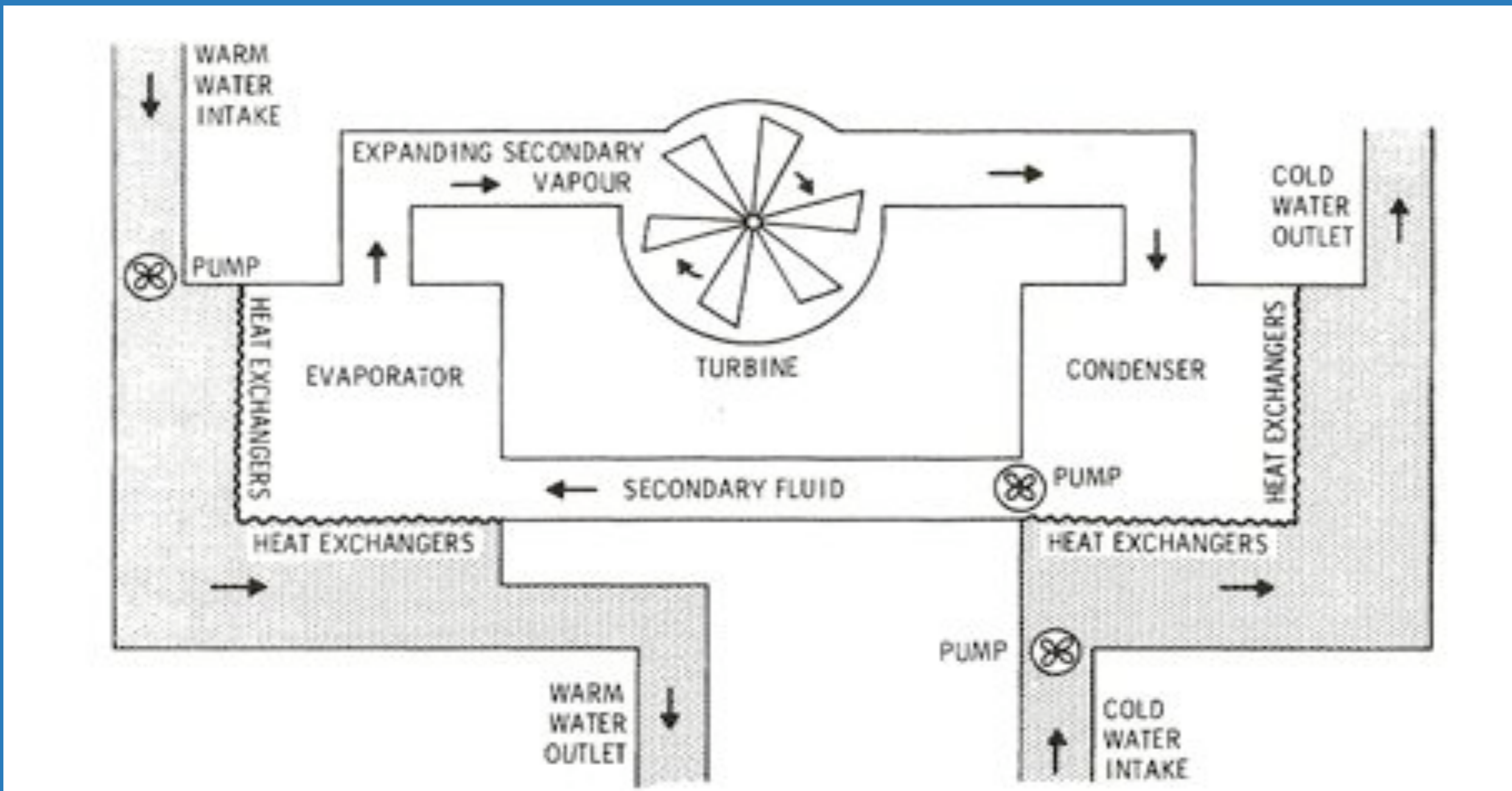
Potential Market Chronology for Ocean Thermal Energy

- **Early market:**
  - Baseload electricity to shore to displace oil-derived electricity (e.g., Puerto Rico and Hawaii) and provide fresh water as a co-product

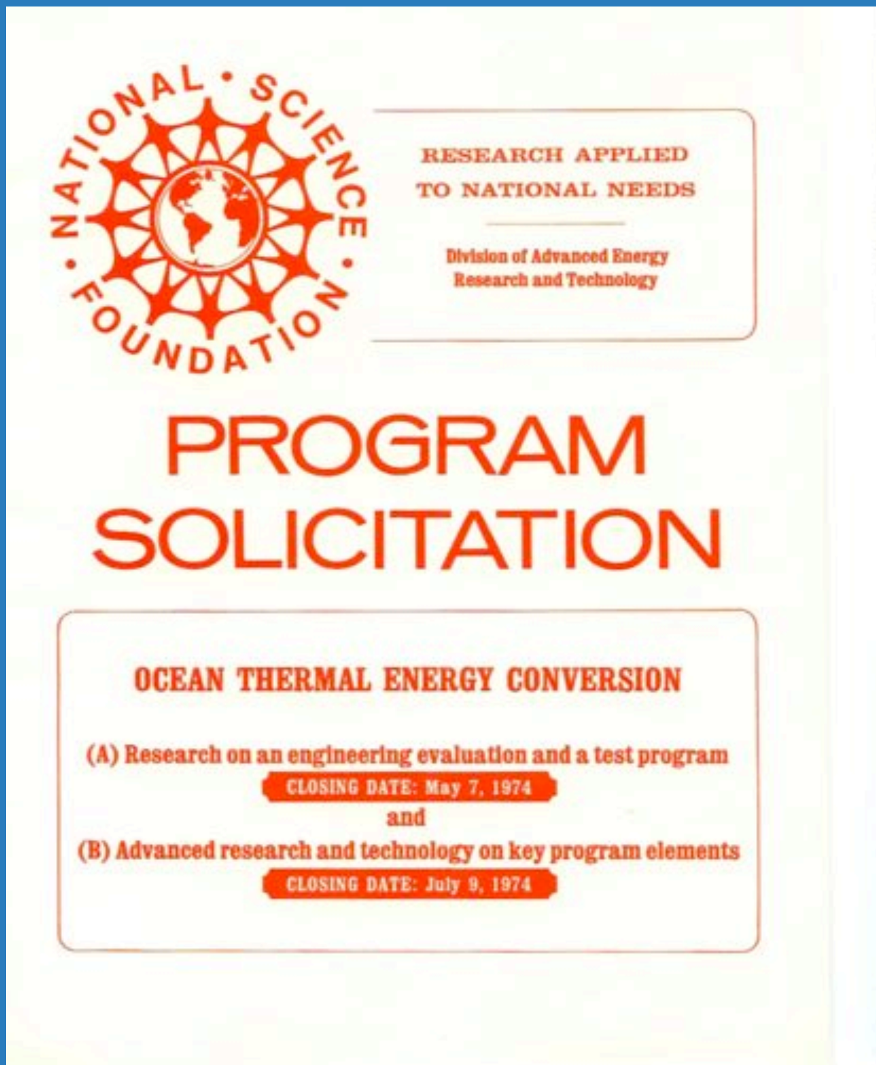
OIL SAVINGS: 40 BBL/day per MWe

- **Near-term market:**
  - Baseload electricity to mainland electrical grids (e.g., from Gulf of Mexico to Florida, Louisiana, Texas)
- **Long-term, potentially vast-payoff, market:**
  - Plantships grazing the high seas manufacturing energy carriers (e.g., hydrogen and ammonia) and energy-intensive products (e.g., ammonia)

Schematic Diagram of a Closed-Cycle Ocean Thermal Power System



RFP to Industry (1974)


NATIONAL SCIENCE FOUNDATION

RESEARCH APPLIED TO NATIONAL NEEDS

Division of Advanced Energy Research and Technology

PROGRAM SOLICITATION

OCEAN THERMAL ENERGY CONVERSION

(A) Research on an engineering evaluation and a test program

CLOSING DATE: May 7, 1974

and

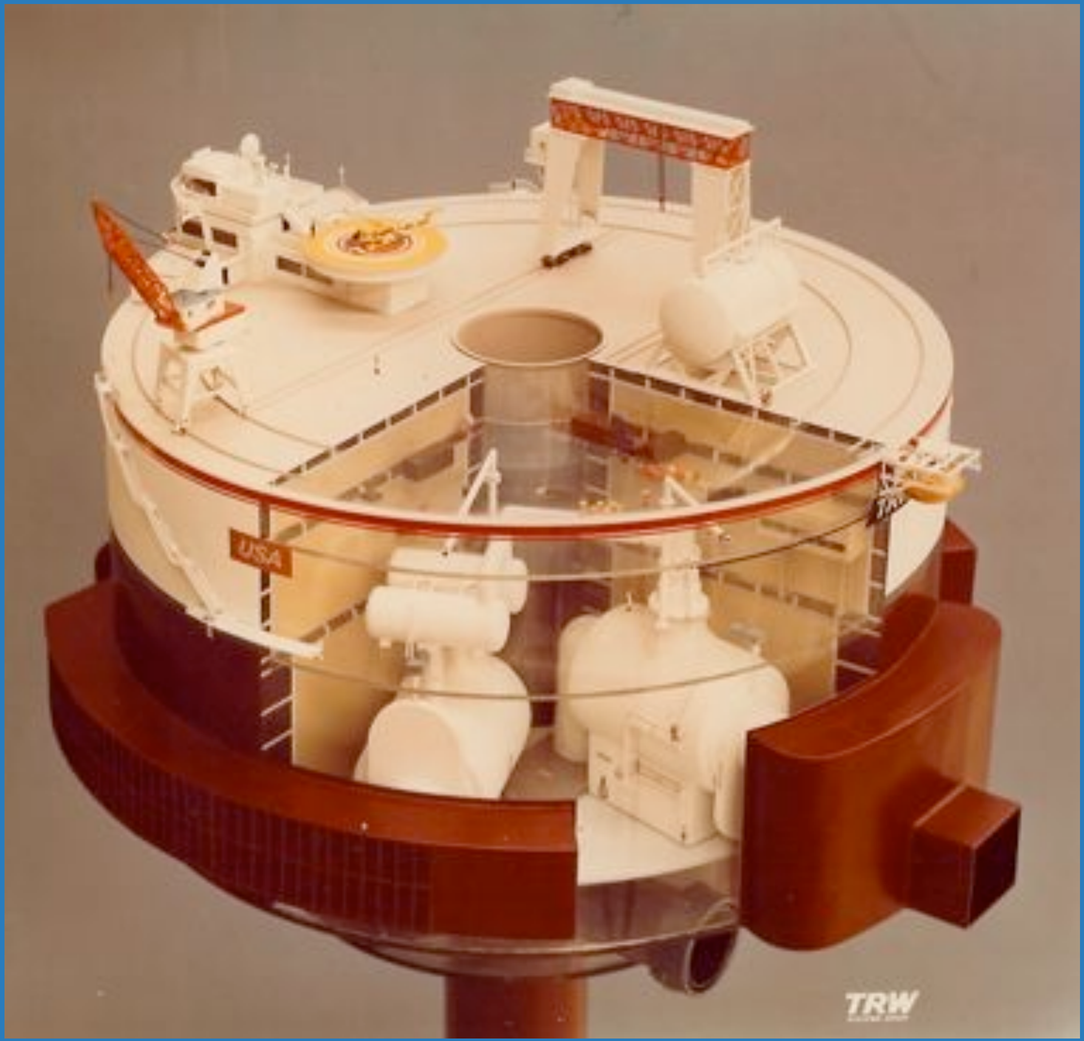
(B) Advanced research and technology on key program elements

CLOSING DATE: July 9, 1974

AWARDS TO:

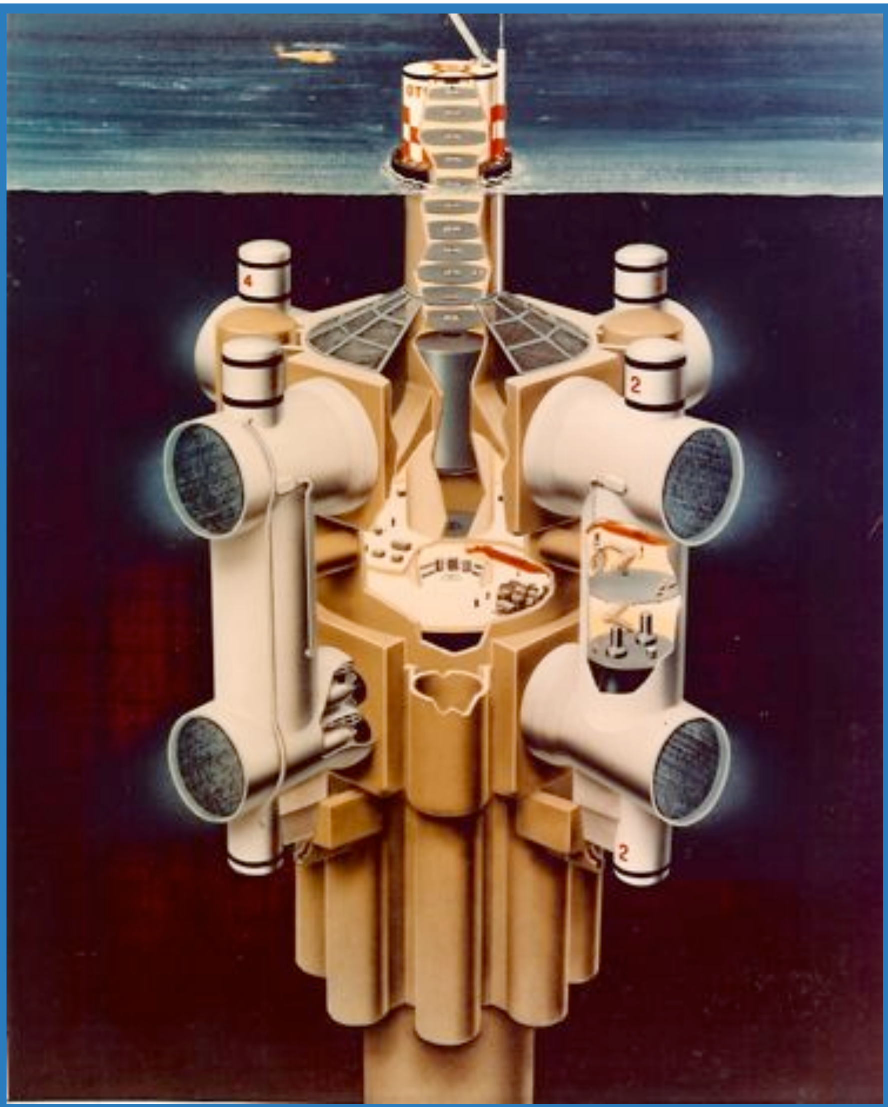
- TRW
- LOCKHEED

TRW Conceptual Design (1975) of an Ocean Thermal Power Plant



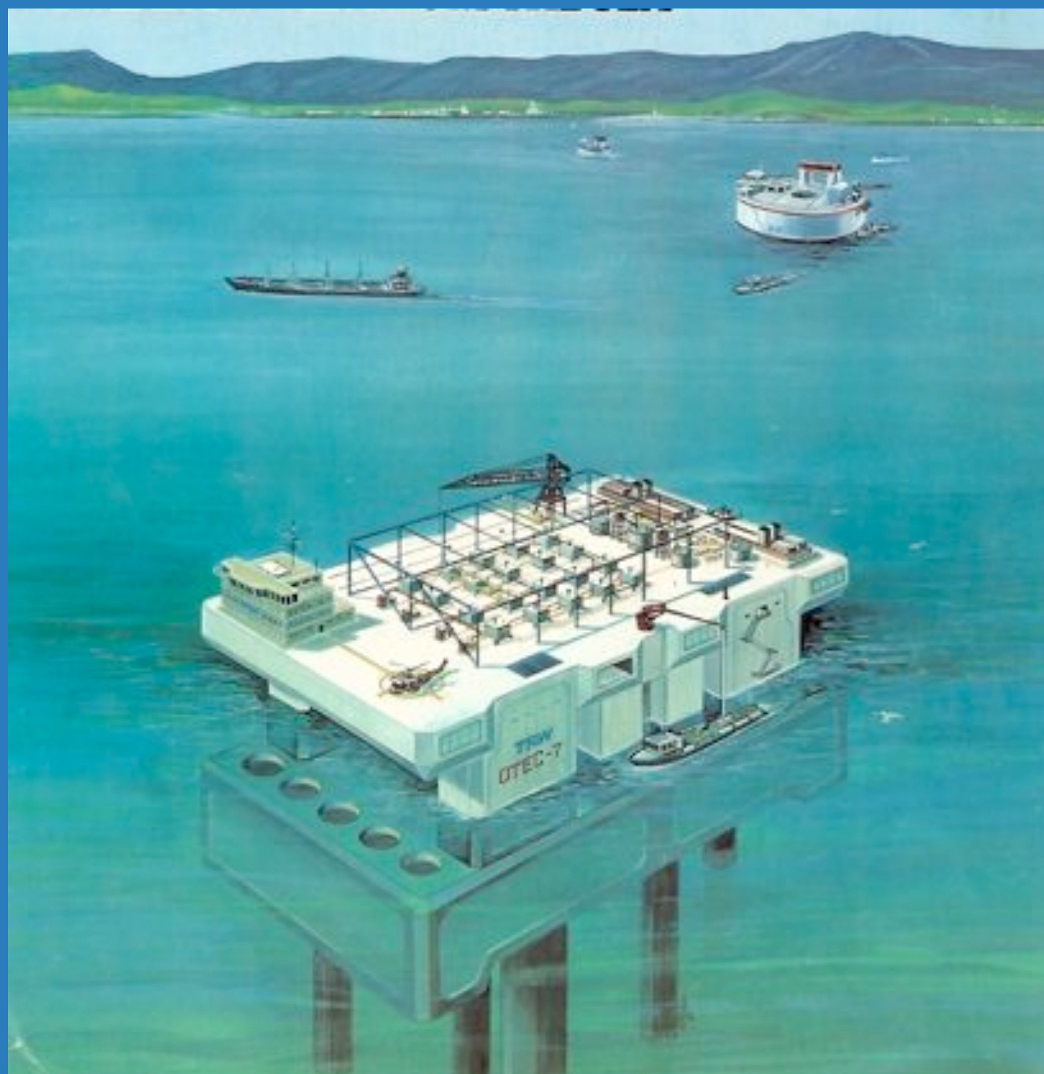
- 100 MWe
- Four power-modules
- Surface platform

Lockheed Conceptual Design (1975) of an Ocean Thermal Power Plant



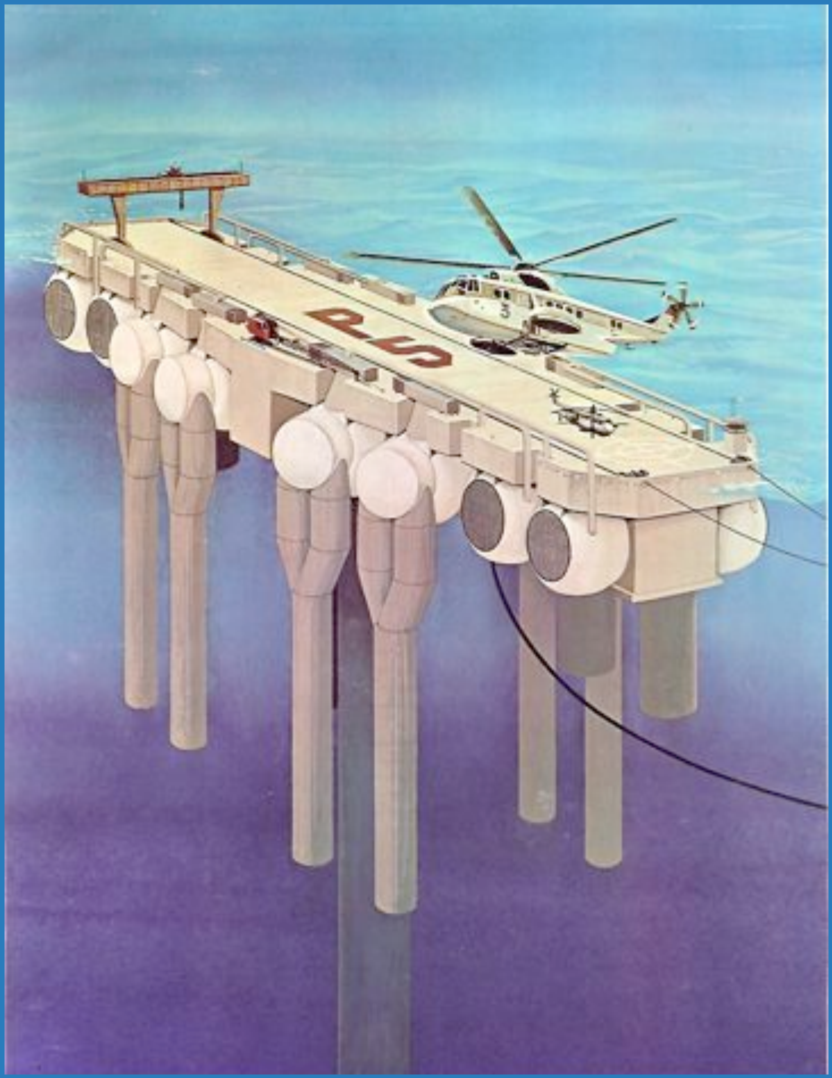
- 265 MWe
- Four power-modules
- Spar-buoy configuration

TRW Plantship Concept for Refining Aluminum



To reduce $AlCl_3$ to Al metal

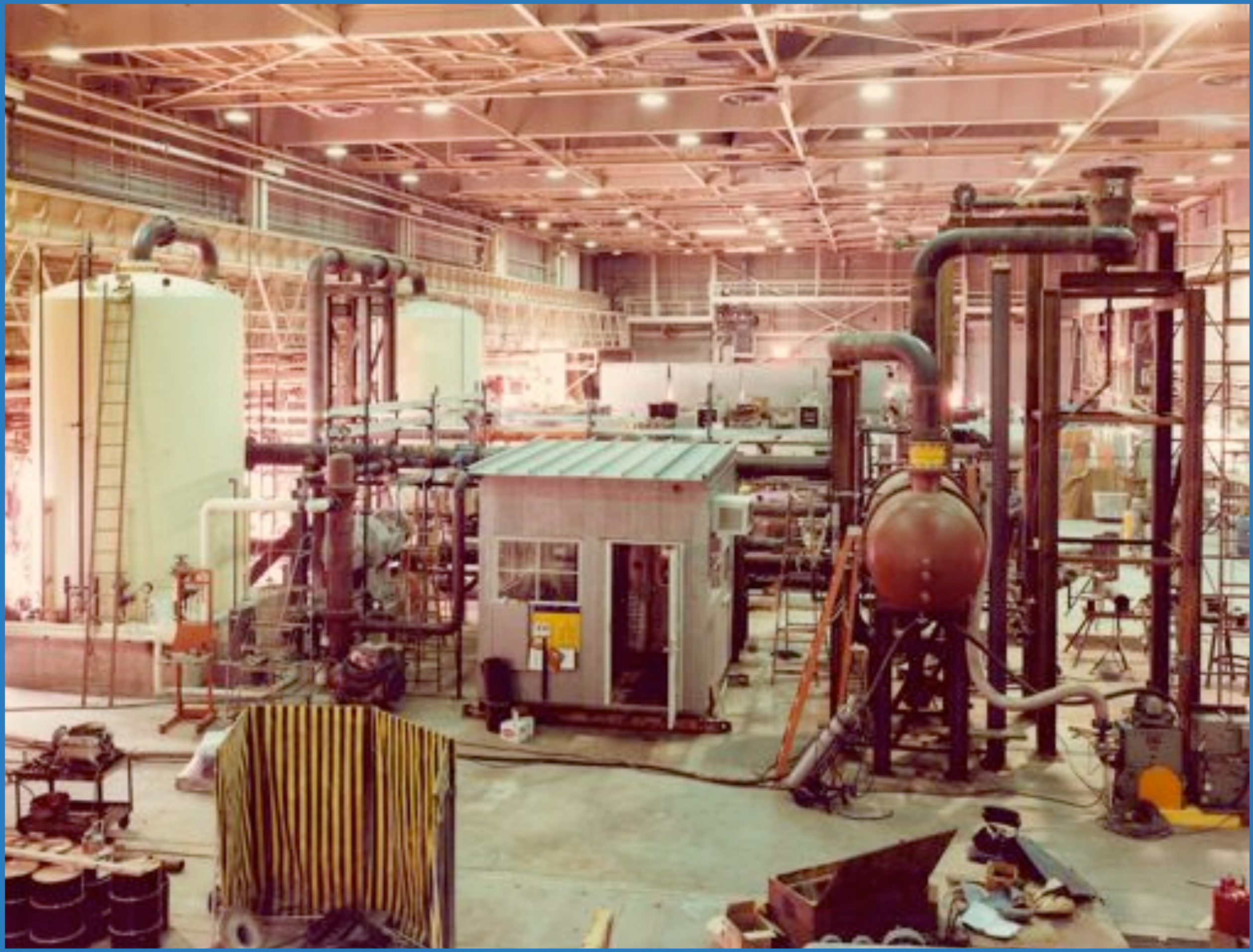
Lockheed Plantship Concept



Technology Requirements/Challenges to Achieve this New Industry

- Heat exchangers designed to withstand corrosion and control biofouling
- Cold water pipe (CWP) design & deployment
- Mooring or dynamic positioning
- Submarine electrical cable
- Coupling of CWP and cable to the platform
- Operability in storms; survivability in severe storms & hurricanes

Heat Exchanger Test Facility DOE/Argonne National Laboratory



Testing capacity: 1 MW thermal

Mini-OTEC system (1979) off Hawaii by a consortium led by Lockheed

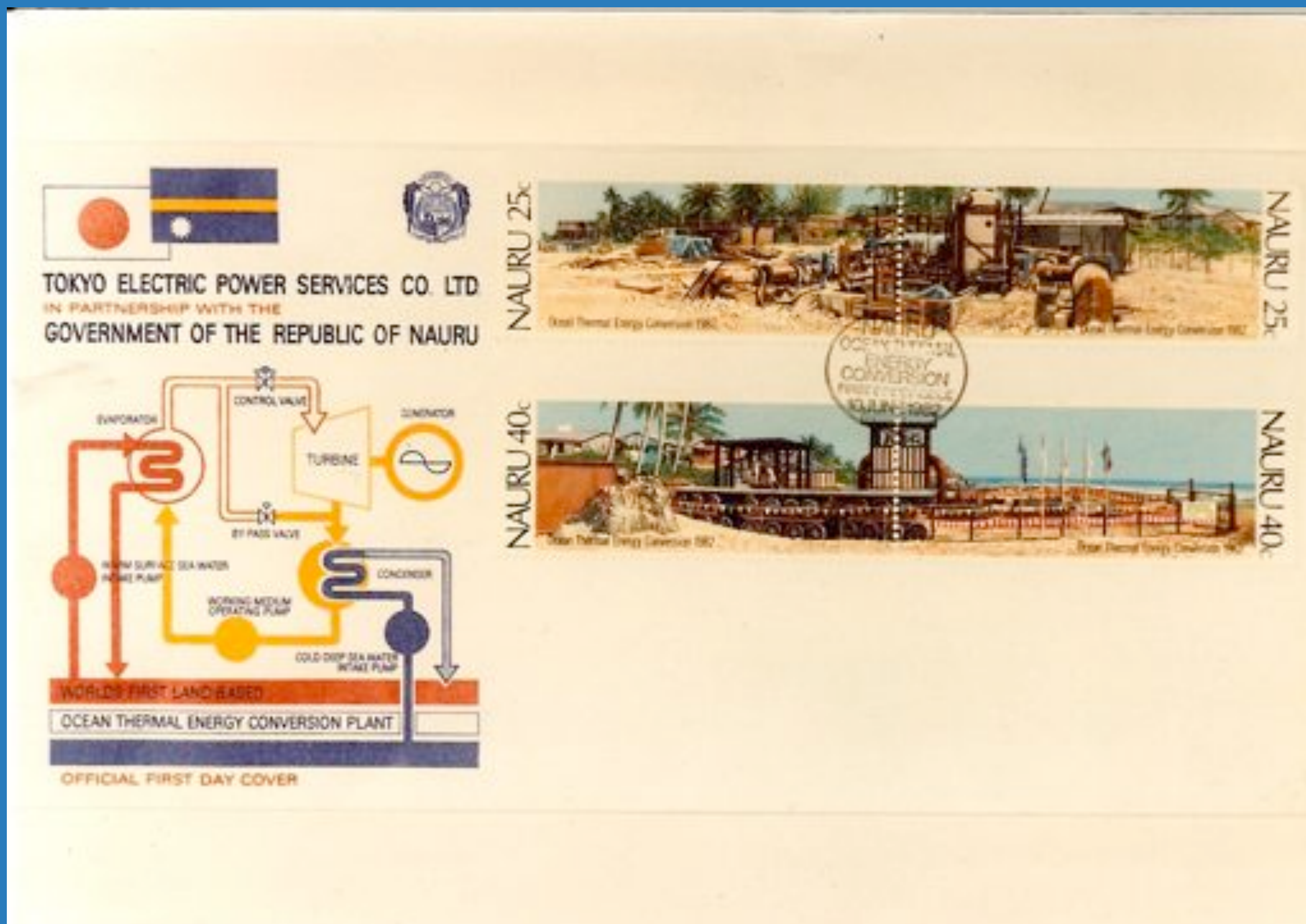
- 50 kWe gross power
- ~15 kWe net power

Nauru Land-Based System (1981)
Tokyo Electric Power Services Co.

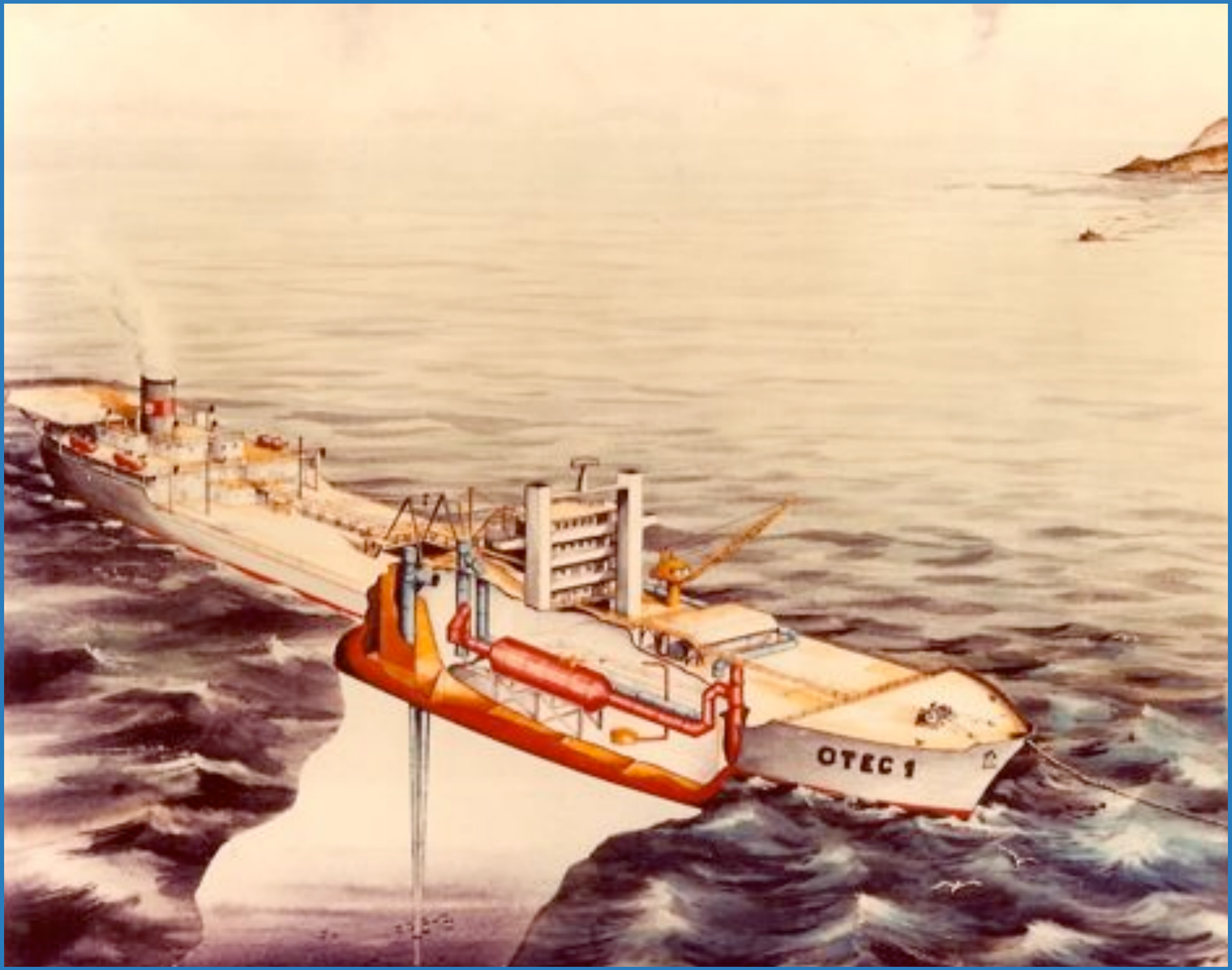
- 100 kWe Gross Power
- 34 kWe Net Power

Republic of Nauru

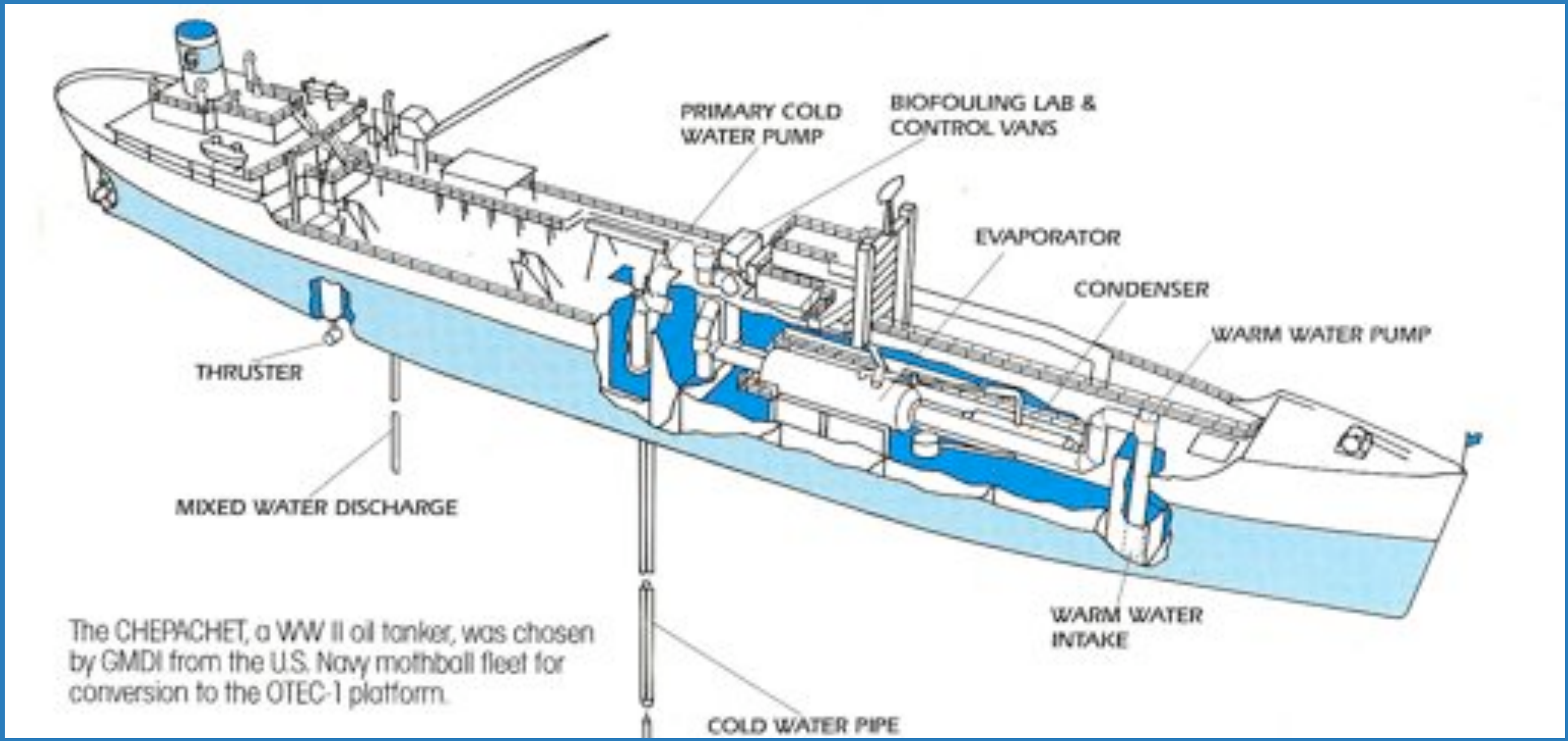
Ocean Thermal First Day Cover (1982)



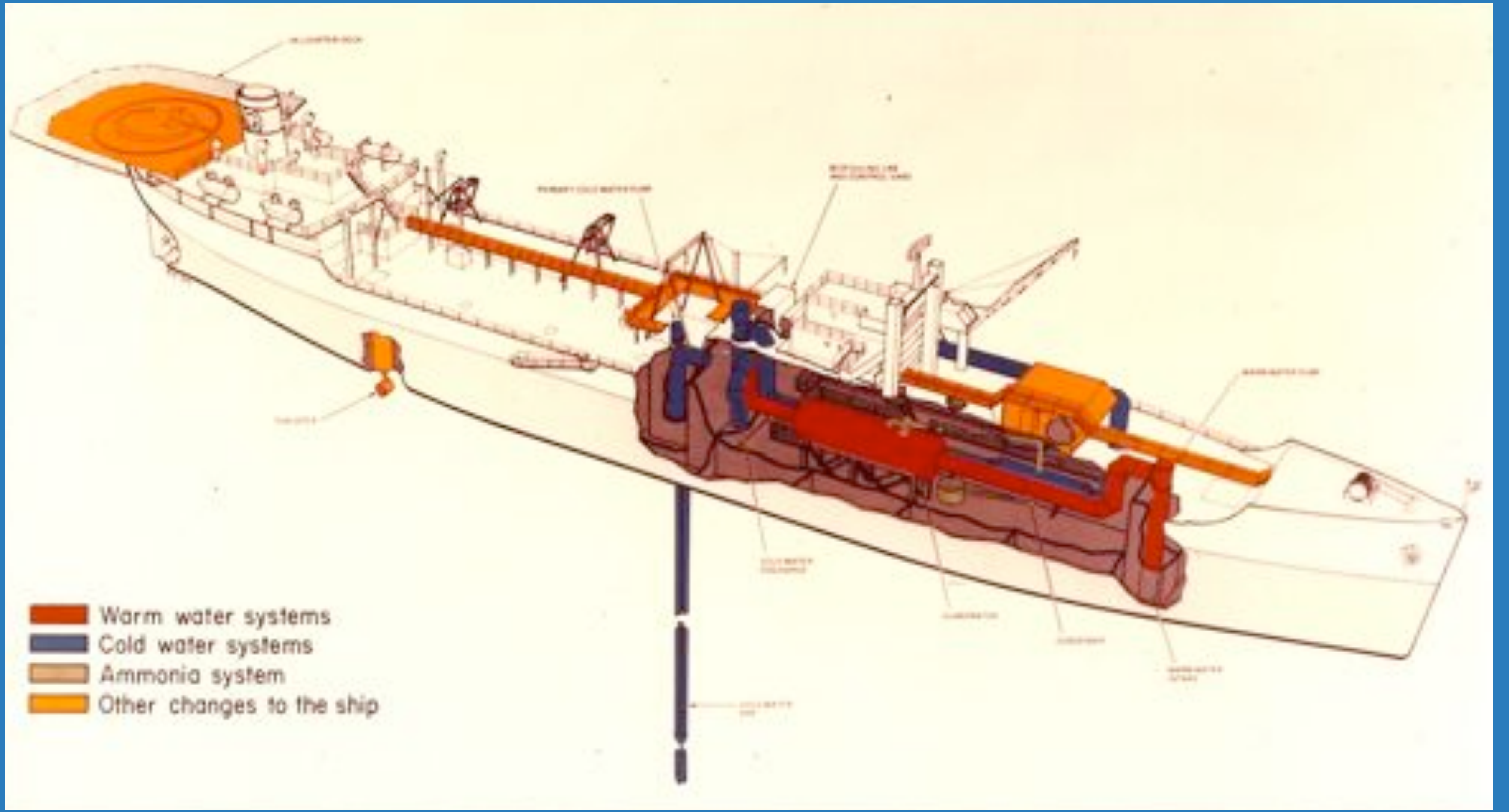
OTEC 1, a Floating 1-MWe Test Facility DOE (1980) Hawaii



OTEC 1 Schematic



OTEC 1 Subsystems



Environmental Aspects of Ocean Thermal Energy

- **Avoid perturbing the plant's temperature environment**
  - **One way would be to mix the seawater effluents and discharge the mixture at an appropriate depth**
- **Avoid liberating CO_2 to the atmosphere or moving cold seawater to the mixed layer**
- **Possibility of *removing* CO_2 from the atmosphere and *sequestering* it in the deep ocean [If *any* technology can do so, ocean thermal plants are well positioned for the job.]**

Power Plant Conversion Efficiency & Energy Cost

- **Efficiency is the percentage of thermal energy converted to electrical energy**
- **Theoretical efficiency is about 6 to 7%**
- **Net efficiency achievable is about 2 to 3%**
- **Net efficiency is important, but it is *not* the economic bottom line**
- ***The economic bottom line is Energy cost (in ¢/kWh)***

Electrical Energy Cost Factors

- The life-cycle Energy Cost of electricity (in ¢/kWh) is the sum of:
  - The power plant's amortized Capital Cost
  - The plant's O&M Cost
  - The Fuel Cost
- For a renewable energy source, the Fuel Cost is zero. But the Capital Cost is often higher than that of a conventional power plant
- Capital Cost targets for early commercial (ca. 100 Mwe) baseload ocean thermal power plants are ca. $10,000/kWe, translating into an Energy Cost of ca. 20¢/kWh

Surmounting the Market-Entry Hurdle

- Previous experiments with small, closed-cycle ocean thermal systems:
  - Mini-OTEC floating plant off Hawaii (~15 kWe net power)
  - Land-based plant on Nauru (34 kWe net power)
  - OTEC 1, a floating 1 MWe test facility off Hawaii (component-testing, without a turbine)

- ***NEEDED: A VIABLE MULTI-MEGAWATT OCEAN THERMAL POWER PLANT***

The Market-Entry-Hurdle Dilemma

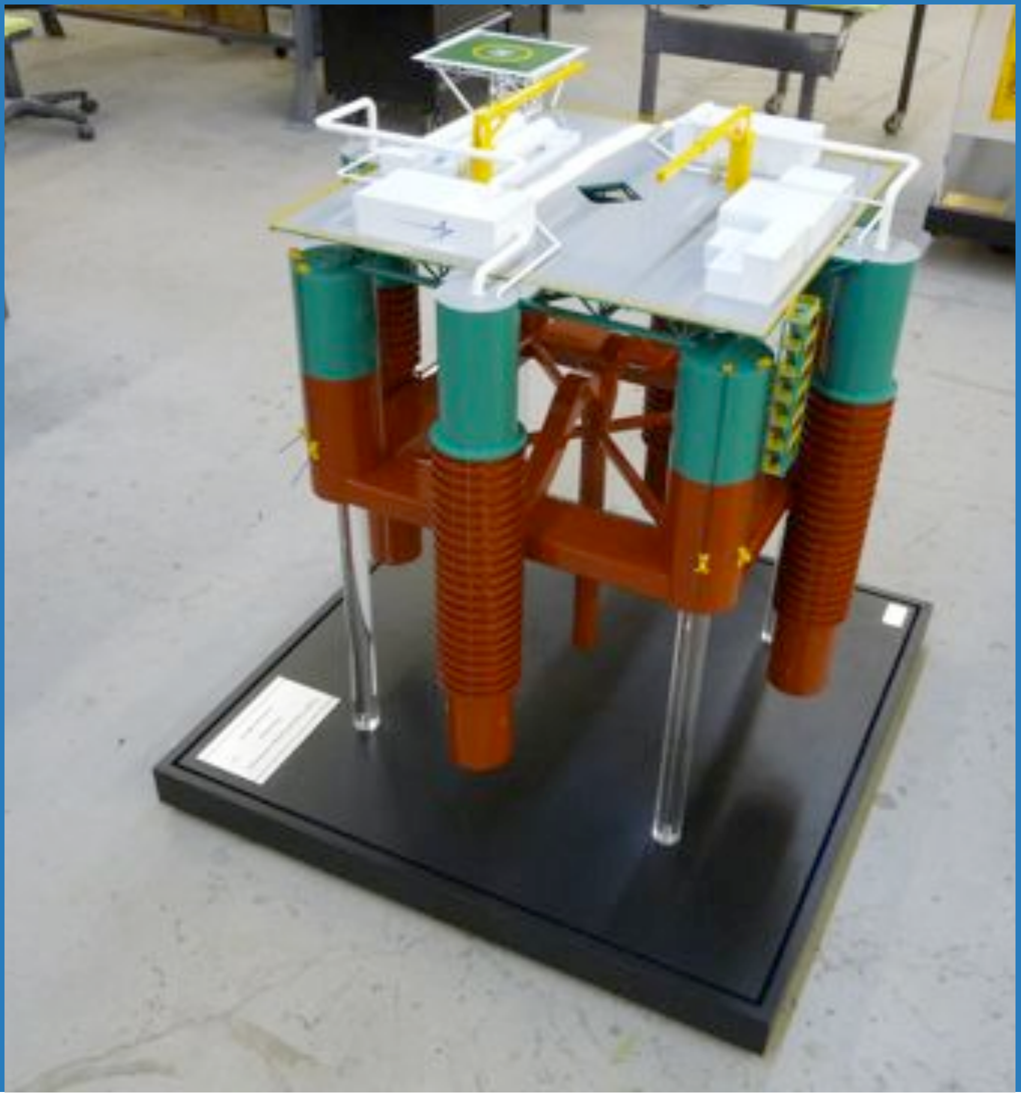
- *A first-of-a-kind 10 MWe power plant will be **sub-economic**, hence will need to be partially subsidized*

The Market-Entry-Hurdle Dilemma

- ***A first-of-a-kind 10 MWe power plant will be sub-economic, hence will need to be partially subsidized***

- ***A first-of-a-kind 100 MWe plant will be close to economic, but involves a larger scale-up and investment***

Photo of a Lockheed Martin model of a 10 MWe pilot plant



A Potential New Ocean Industry

Energy FROM the oceans

to replace

Energy from ACROSS the oceans